Route Descriptions, Spatial Knowledge and Spatial Representations of Blind and Partially Sighted People: Improved Design of Electronic Travel Aids

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Abstract

The results presented here were obtained from an experimental study of blind people's experiences on two routes with very different characteristics. They are intended to answer three research questions on how blind people identify environmental features while travelling and use environmental information to form spatial representations, and the implications for the design of electronic travel aids to better support mental mapping of space. The results include detailed discussions of the mainly tactile and auditory information used by blind people to identify objects, as well as the different combinations of sensory information used in forming mental maps, the approaches participants used to do this and the sensory modalities involved. They also provide a categorisation of the main features in participants' descriptions of the two routes. The answers to the three questions include a discussion of the relationship between the sensory information used in route descriptions and mental maps, and the implications of the results for the design of electronic travel aids to support mental mapping, including suggestions for new types of aids and guidelines for aid design.

Index Terms: blind, partially sighted, object identification, mental models, route descriptions, sensory information.

ACM CCS: user studies, transportation, people with disabilities, user characteristics, user models.

1. Introduction

Mobility is an important aspect of modern life. Most people need to travel to take part in activities, including employment, education, social, leisure and daily living activities such as shopping, and this can involve short or long distances. Being able to form representations of the environment you are travelling through is helpful in learning routes, locating facilities, finding shortcuts and returning to the right path if you get lost.

There have been significant advances, including by the authors (Hersh, 2020ab) from the earlier position of questioning whether blind people are capable of understanding and representing space. There is a body of research on the spatial performance of blind people e.g. studies reported in (Hersh 2020a; Shinazi et al. 2016; Thinus-Blanc and Gaunet 1997). However, there is still a focus on the relationship of early and late blind people's performance to that of sighted people. This has led (Shinazi et al. 2016) to the convergent, cumulative and persistent models, all of which assume that vision has a unique role in spatial skills and that blind people start with poorer spatial skills, but can catch up with experience (convergence) show increasingly worse performance over time (cumulative) or remain at the same level of disadvantage despite experience (persistence).

Many, though by no means all, studies have shown worse performance by early blind participants, and studies have sometimes obtained conflicting results e.g. (Thinus-Blanc and

Gaunet 1997). In addition, many studies have very small sample sizes of between one and eight participants, complicating comparisons and generalisation of conclusions and require all groups to use the same strategies (Schinazi et al. 2016). For instance pointing is frequently used in experiments on spatial inferences. However, pointing is a visual strategy which early blind people, in particular, may experience difficulties with. Thus the relatively poorer performance of early blind people on spatial inference tasks involving pointing may be due to difficulties with pointing rather than their spatial inference abilities.

The diversity of the blind population also complicates comparisons of different studies (Schinazi et al., 2016). However, there is also a lack of comparative studies of different groups of blind people to investigate how factors, such as the extent and type of early experience of exploration, type and age of start of orientation and mobility training and extent of access to tactile maps, affect development of spatial representations and performance on travel tasks. In addition, it would be useful to study the relationship between navigation strategies and performance (Schinazi et al., 2016), including to investigate the strategies used by expert blind travellers on real routes.

It should also be noted that spatial representations depend on the available information and that the greatest challenge to blind people's spatial cognition is posed by a lack of accessible information, rather than lack of vision, (Giudice, 2018). For blind people access to spatial information depends, at least in part, on having appropriate travel aids (Hersh and Johnson, 2008; Pissaloux et al., 2016) and good orientation and mobility training (Ramirez et al, 2011). For instance, there has been limited investigation of the impact of access to tactile maps, which are not generally available (Lobben and Lawrence, 2012), on the development of 'map' or 'survey' representations.

Studies show a preference by blind people for egocentric representations (Thinus-Blanc and Gaunet 1997) and greater accuracy and speed than sighted people in processing egocentric small space information. Congenitally blind people can use allocentric representations (Passini and Proulx, 1988; Tinti et al., 2006), but are less accurate in processing allocentric large space information and slower in processing both egocentric and allocentric large space information (Iachini et al., 2014). The lower performance on large scale space may be due to limited experience of exploring them, including as a result of the limited availability of tactile maps and limited opportunities to explore at a young age. Several studiess indicate the importance of early opportunities to explore and early orientation and mobility training and their ability to improve spatial skills (Casey, 1978; Nielsen, 1991)

Blind and sighted people have been found to have similar abilities to construct spatial mental models (Noordzij et al., 2006), which are detailed and accurate for at least some blind people (Jaccobson, 1998). Much of the research on the performance of spatial tasks supports the amodality hypothesis that spatial images are sense independent and spatial coding mechanisms do not require visual experience (Loomis et al., 2012, 2013).

In summary, there are still outstanding questions about the relationship between the spatial abilities of early and late blind and sighted people. However we think that more fruitful research directions would focus on the spatial abilities of blind people, what affects them and how best they can be developed. This gives a number of research questions, including the following:

Spatial understanding and representations

- What types of spatial understanding and representations blind people develop in real travel situations and how they do this, including the sensory modalities involved.
- How effective these representations are at supporting travel and whether some types of representations are more effective than others.

- The factors that affect blind people's spatial understanding and representation and how this can be used to support their development.
- The relationship between different navigation strategies, spatial representations and successful travel outcomes.
- How travel aids can better support developing spatial understanding and representation particularly of the above types and what types of travel aid can best do this.

Improving spatial skills

- The roles of experience/other factors and nature/inheritance in leading to blind people having particularly good spatial skills.
- Investigation of the spatial skills of blind people with excellent spatial skills, including the small number of blind orientation and mobility instructors, and any common causal factors.
- Ways of improving spatial skills.

We would also strongly encourage research to use participatory approaches with blind (early and late partially sighted and deafblind) people and would like to see more of them entering this field of research.

This work aims to make a significant contribution to filling these gaps through analysis of the results of an experimental study involving blind people's experiences on two routes with very different characteristics. It further uses this analysis to make recommendations for the development of ETAs to better support the development of mental models. The paper will therefore answer the following research questions:

1. How do blind people identify environmental features while travelling and what sensory modalities do they use to do this?
2. How do blind people use sensory, route and other environmental information to form spatial representations and the sensory modalities used in these representations?
3. What are the implications of the responses for the design of travel aids to better support the development of mental models of space?

2. Literature Review

2.1 Cognitive maps

The concept of a cognitive or mental map was first proposed by Tolman (1948). The research has generally considered sighted people, but there is evidence that blind people also develop mental maps e.g. (Casey, 1978; Hersh, 2020a; Lahav and Mioduser, 2005; Passini and Proulx, 1988). Definitions are often vague and have been repeatedly reformulated (Schinazi et al., 2016). In this paper the term mental map will be used for the representations of space developed by individuals and no particular assumptions will be made about the structure of other properties of these representations.

The hippocampus is increasingly being considered the area of the brain responsible for spatial mental maps. They have been linked to grid, head and border cells in cortical and other brain structures and hippocampal cells have been identified which encode distance and direction to navigational goals (Epstein et al., 2017). Although research seems to be lacking, there is no obvious reason why blind people should use different spatial regions. There is indicative evidence that the hippocampus represents a series of mental maps, each tied to a specific spatial context rather than one global map (Ekstrom and Ranganath, 2018). For instance, someone with cognitive maps of several different cities generally considers each map separately, though they may combine their mental maps of different areas within one city. There is evidence that blind people consider global representations in the context of a particular route or a combination of routes in the same area (Hersh, 2020a) rather than more widely. The hippocampus prioritises the use of encoding based on four space-time dimensions, as is most relevant to mental maps of space, but can use other dimensions (Ekstrom and Ranganath, 2018).

There is still a tendency for the literature to start from the perspective of visual understanding of space and consider blind people's spatial skills 'in the absence of vision' rather than directly investigating the spatial representations used by blind people. The blind population is very diverse on a number of factors, including education, type and age of onset of visual impairment and extent of mobility skills (Shinazi et al., 2016), as well as their access to tactile maps and environmental exploration, and this diversity may affect their mental maps. However, the literature has tended to concentrate on between group differences (early and late blind and blindfolded sighted) and paid limited attention to within group differences. The latter may be more significant for designing more effective travel aids and supporting blind people to improve their travel skills. It has been suggested both that blind people are disadvantaged by the sequential nature of hearing and touch compared to vision and that all sensory modalities are both sequential and simultaneous to some extent (Shinazi et al., 2016).

Having a mental map including features such as overall structure, landmarks and relative position, can facilitate mobility and orientation (Lahav and Mioduser, 2008). The quality of this mental representation has been found to effect the quality of mobility (Picinali et al., 2014). Cognitive maps are related to the surrounding environment by landmarks, which are important for both blind and sighted people, though blind people tend to use landmarks from more sensory modalities than sighted ones (Hersh, 2020a). The cognitive maps of visually impaired people include basic elements, such as streets, buildings, parks, bus stops and fixed obstacles (Papadopoulos, 2004). Various studies (Papadopoulos et al., 2018) show that blind people use salient external cues to code space. They are dependent on the available information and may be limited when accessible information is not available.

Blind people have been shown to prefer route (egocentric) approaches to survey (allocentric) ones (Besse et al., 2017), possibly due to obtaining environmental information serially (Leo et al., 2019). This may also be due to the need to reduce cognitive load by focusing on essential information. However, blind people on average, though not all of them, have been found to perform better on some pointing tasks when using survey approaches (Chiesa et al., 2019). This indicates successful use of survey approaches, but the differences in performance in small groups cannot be used to infer whether this is due to choice of strategy, differences in spatial abilities or participants with better spatial abilities choosing better strategies. Drawing on existing spatial knowledge of how environments are likely to be structured can be very useful in mental mapping, but cause problems when real environments differ from expectations.

2.2 Environmental representations and tactile maps

Both blind and sighted people can learn an area by walking through it or using a representation in advance. The earliest representations developed specifically for blind people were tactile maps, which are still unfortunately not available to a large extent (Lobben and Lawrence, 2012). It is generally recognised that tactile maps can support spatial learning. However, they also have limitations. For instance, they are not interactive, cannot be updated with the user's movements or new information (Giudice et al., 2020), and can provide less information than a visual map of the same size while maintaining readability. Labels are generally in Braille, which few blind people read (Jacobson, 1998).

Alternatives include virtual multimodal or acoustic environments and (interactive) audio tactile maps. Interactive maps on digital displays have the advantages of multimodal capability, easy updating, implementation on readily available, easily portable devices, such as tablets, and map zooming, panning, scrolling, search and location functions (Giudice et al., 2020). Hybrid versions have a tactile map overlay on a digital tablet which provides multi-modal audio-tactile information. Digital interactive maps provide audio and haptic information without a map overlay. Tactile/haptic information can be provided in various ways, including the phone/tablet built-in motor vibrating whenever the user's finger contacts an onscreen visual element. This has the advantage of using existing portable devices, but is limited by providing only one point of contact. Recommendations for multimodal systems to support navigation include (Kuriakose et al., 2020) portability, easy addition of new features or modalities without overloading the user, flexible customisation options for user settings, multiple modalities including audio feedback and the ability to select the most appropriate mode of interaction for the current circumstances. Users may require training to familiarise themselves with new systems, such as virtual interfaces (Guerrón et al., 2020).

Studies have shown the value of the different devices in supporting mental mapping and frequently also that there are sometimes differences in the mental maps obtained from different approaches, for instance from a tactile map and walking through the area (Papadopoulos et al., 2018). However, studies have generally comparatively assessed two or three approaches and conclusions cannot be extended more widely. Approaches which have been shown to support (accurate) mental mapping include audio-tactile maps with environmental sounds associated with particular locations (Griffin et al., 2019), hybrid interactive and interactive maps on a touchscreen device with audio and vibratory input (Giudice et al., 2020), moving through an environment, virtual reality simulations for real spaces, which may be more suitable for room sized than larger spaces (Cobo et al, 2017) and active navigation of a virtual acoustic environment with a joystick (Picinali et al, 2014), Single finger exploration on a touchscreen has been found to be satisfactory (Giudice et al., 2020), particularly if the other hand is used as an anchor point to support map panning (Palani and Giudice, 2017).

An audio-tactile map with environmental sounds associated with particular locations has been found to improve recollection and knowledge of a virtual environment compared to a tactile map with verbal descriptions (Griffin et al., 2019). There is some evidence of the greater effectiveness of audiotactile maps on a touchpad in accurate mental mapping than purely tactile maps or walking through an area (Papadopoulos et al., 2018). Moving through an environment and active navigation of a virtual acoustic environment with a joystick, but not passively listening to binaural recordings can be used to produce mental representations with correct topological and metric properties (Picinali et al., 2014). There is some evidence (Cobo et al., 2017) that distant exploration of a virtual reality representation of different types of rooms leads to the detection of more obstacles and speeds up the exploration compared to exploration of the space at cane distance. Exploration of a room using a multi-sensory virtual environment has been found to very significantly reduce exploration time and result in accurate verbal descriptions of room size and shape. Moving around the room has been found to relt in more detailed and specific information about objects and more participants locating objects in the environment (Lahav and Mioduser, 2008).

2.3 Route knowledge, familiar and unfamiliar routes

Both blind and sighted people most frequently use familiar routes to familiar destinations (Long and Giudice,1997), but the distinction between familiar and unfamiliar routes is particularly important for blind people. Analysis of interviews with 100 blind and partially sighted people found that they had a number of familiar routes they used regularly and did not feel comfortable about travelling unaccompanied on unfamiliar routes (Hersh, 2020a). Interviews with 24 blind people found that their main worries about travel in familiar areas were unexpected obstacles and avoiding obstacles, whereas in unfamiliar areas they were getting lost and having to ask for information. In both cases they were concerned about public transport and personal safety/areas with few people (Johnson and Petrie, 1998).

In familiar areas travellers are able to look out for obstacles to avoid them and expected landmarks to check they are on the right route and to match what they encounter to their expectations from route knowledge. They can then use problem solving strategies if there are (significant) differences (Long and Giudice, 1997). Sighted people can generally use hard copy or online maps to prepare for travel and obtain information about unfamiliar areas, but the availability of tactile maps is limited (Lobben and Lawrence, 2012). Blind people generally also require considerably more information for safe travel along a route than sighted people (Fortin et al., 2008).

The study of 100 blind people mentioned above found that they wanted to either be accompanied or taught unfamiliar routes. They generally considered it only worth learning routes they were going to travel regularly. They therefore preferred to be accompanied on unfamiliar routes they were using on a one-off basis and to learn routes they would be using regularly with the assistance of an orientation and mobility instructor or another person (Hersh, 2020a). The number of times a person needed to be shown a route varied with the person and probably also the route complexity. They generally needed the instructor to point out obstacles and landmarks so they could learn their locations (Hersh, 2020a). When no-one is available some blind people will not travel, whereas others obtain as much information as they can in advance and ask for information and assistance when they arrive.

2.4 Overview of Electronic Travel Aids

The most commonly used travel aid is still the long cane (Hersh, 2015). It has a number of advantages, including simplicity, robustness and reliability, as well as the limitations of not providing information on distant or high level obstacles or to support way finding and navigation. A number of electronic travel aids (ETAs) have been developed, but their use is limited. The reasons include high costs, limited benefits compared to the long cane, weight and the lack of free or low cost training.

2.4.1 Phase 1: Obstacle Avoidance Devices

Successful travel requires both obstacle avoidance and navigation/wayfinding and there are likely to be advantages in both types of information being available from a single device. Travel aid development can be divided into three overlapping phases (Pissaloux et al., 2016). The first phase focused on obstacle detection devices with additional functionality compared to the long cane. Many of these devices are in the form of a cane e.g. the laser cane (Hersh and Johnson, 2008), the smart cane (Terlau *at al.* 2008), the ultracane (Hoyle and Dodds, 2006) and the Tom Pouce and Télétact (Farcy, 2006). Environmental information is obtained from infrared, ultrasonic and/or laser sensors and communicate it to users via vibration or non-speech sounds. Some of the more recent devices use camera vision sensors and signal processing e.g. (Arditi and Tian, 2013; Kumar *et al.,* 2011) and additionally involve object recognition and scene representation functions. A few aids e.g. Smart Environment Explorer Stick (Yusro *at al.*, 2013) combine obstacle avoidance and wayfinding/navigation functionalities. This phase also includes robotic devices such as the GuideCane (Shoval et al., 2003) and CaBot (Guerreiro et al., 2019) with both navigation and obstacle avoidance functions. CaBot uses a map of the location and guides users with vibrotactile feedback, whereas the GuideCane is particularly intuitive, as it has enough mass for the user to feel and follow its movements.

2.4.2 Phase 2: Navigation and Wayfinding Devices

The second phase involved the development of navigation and wayfinding devices using two distinct approaches with overlapping functionality (Hersh, 2009). Global positioning systems (GPS) and other global navigation satellites locate the user and have point of interest and other functions. Trekker Breeze, Trekker GPS, Navigator and Captain and software such as wayfinder on a mobile device (Gallay et al., 2013; Pissaloux et al., 2016) are suitable for blind people. Environmental information beacons locate a point in space, using active or passive radio-frequency identification (RFID) tags or infrared transmitters (Fernandes et al., 2019) e.g. the Talking Signs system and the Haptic Pointer Interface (Pissaloux et al, 2016). They may have additional functions, such as providing information about located facilities or requesting vehicle doors are opened. More recently Bluetooth low energy (BLE) beacons have been used in navigation systems, particularly for large complex indoor environments e.g. (Cheraghi et al., 2017; Murata et al., 2019).

GPS unfortunately have insufficient resolution, leading to a lack of accuracy and, for instance, users sometimes being informed of turnings after they have passed them (Gullay et al., 2009). This lack of accuracy reduces the support that can be provided for mental mapping. This could be improved by using visual landmarks with precisely known positions from global information systems to update the GPS estimate, as in the Navig system (Katz et al., 2012).

2.4.3 Phase 3: Apps on and Vision Sensors Linked to Smart Mobile Devices

BLE systems generally involve apps on smartphones, giving the third or current phase of apps on smart mobile devices and vision sensors linked to smart mobile devices e.g. (Sato et al., 2017). Many of the apps provide specific contextual information which is relevant to both blind and sighted people e.g. Find my bus and Find my busstop. A study of 259 blind people found that 13.5% of them used GPS navigation apps such as BlindSquare and Sendero GPS, but was unrepresentative of the blind population (Griffin-Shirley et al., 2017). A study with 466 participants found that the overwhelming majority of them were increasingly using smartphones and tablets rather than assistive devices (Martiniello et al., 2019). The applications mentioned did not include travel and the study was restricted to existing users of smartphones and tablets, but it illustrates the potential. However, appropriate design for compatibility with audio and tactile output and to take account of their travel strategies is required for use by blind people. This is particularly relevant, as blind and sighted people have different strategies and use different types of information in navigation (Williams et al., 2014).

Thus, phase one involved mainly hardware, phase two a combination of hardware and software and phase three purely software, with the hardware on an existing mobile device. There is an increasing trend toward the use of 3D vision sensors including in navigation on mobile devices (Fernandes et al., 2019). A number of wearable travel aids have been developed e.g. Dakopoulos and Barbakis 2009; Tapu et al. 20200, particularly over the last decade, but they have not yet gone beyond the prototype stage. Most of them include obstacle avoidance functionality, but in many cases this does not go beyond that of the long cane.

The increasing use of camera vision sensors has supported a move to using devices for object recognition and scene description in addition to obstacle avoidance. Some phase 1 devices with a large number of sonars, such as the NavBelt (Shoval et al., 2003) were able to do this to some extent. However, camera vision has much greater potential and has led to devices, such as the Range-IT (Zeng et al., 2017), with walking and exploration modes, The latter mode provides detailed verbal output, but generally requires users to stop walking to use it.

To be successful future ETAs will probably need to combine the long cane advantages of low cost, light weight and minimal maintenance requirements with improved functionality. They should also provide information in a way that supports the formation of spatial representations or mental maps (Hersh, 2020a). This requires understanding of how blind people form mental maps as well as the types of information useful for successful travel. It has been suggested (Strelow, 1985; Welsh and Blasch, 1980) that the latter includes information about obstacle locations, the path surface, landmarks and to support walking in a straight line. Information about obstacles should cover objects with which the person could collide, so from ground level to head height in front and at their sides. Information about the route surface is likely to have much greater relevance to blind people than sighted people. For instance, changes in the surface texture or up or down slopes could be used as landmarks.

Like sighted people blind people use landmarks. However, they use landmarks from a variety of sensory modalities, particularly touch and hearing, rather than mainly visual landmarks, though those with some vision will also use visual landmarks, for instance in the form of light and shadow (Hersh 2020b). Both blind and sighted people need information to keep walking in a straight line, but use different types of information to do this. Blind people most commonly use shore lines such as walls or grass verges (Williams et al., 2014) which they can maintain at a constant distance using the cane.

Blind people need sufficient relevant information to form useful mental maps, as well as structures and tools to do this, including those provided by orientation and mobility training and ETAs. This and the previous section have discussed some of the advances in the understanding of blind people's spatial representations and development of systems that can support advanced exploration of spaces and mental map formation. However, there are still significant gaps and a need for further work, including on the design of ETAs to support mental mapping.

2.5 Contributions of the paper

The main contribution of the paper is using experiments on two real routes to answer the three research questions presented at the end of Section 1. These questions cover the identification of environmental features while travelling and the sensory modalities used to do this; the sensory, route and other environmental information used to form spatial representations and the spatial modalities in these representations; and the implications for travel aids. It can be considered a follow-up to the results presented in (Hersh, 2020ab), particularly (Hersh, 2020a), which are based on interviews with 100 blind and partially sighted people obtained from a wider project involving 300 interviews. This work showed the need for experimental work involving, descriptions of the same routes by all participants. The results presented here are generally consistent with this earlier work, but include different types of details, including discussion of object identification and the relationships between the information used in route descriptions and mental maps. The use of the same route for all participants in this work allows comparisons, whereas the route and area descriptions in the earlier work are based on a variety of very different routes and areas. In addition, the suggestions for the design of ETAs presented here are more detailed and specific.

There is very little in the literature that is directly comparable. The paper that comes closest to some aspects of the contribution is probably (Kan-Kilic and Dogan, 2017). They also consider two real urban routes of similar character to ours, but their focus was the impact of features of urban environments on wayfinding strategies and they do not consider object identification or the implications for the design of travel aids. They also provide considerably less detail on the ways in which blind people use sensory information to form mental maps.

A survey of the use of olfactory cues to support wayfinding was based on a focus group, questionnaire and interviews (Koutsoklenis and Papadopoulos, 2011). they identified the 10 most significant odours and suggested that route descriptions provided to blind people should include information about odours. While it has some relevance to the design of ETAs, this work has a considerably narrower scope than this paper. A comparative study of the use of ‘route’ and ‘survey’ information by blind and sighted people (Steyvers and Kooijman, 2009) used descriptions of a fictitious environment which were read out rather than experiments in a real environment. It focused on learning and accuracy with the two styles of description rather than the sensory information used in mental models and did not consider object identification and the design of ETAs.

There is a body of literature which considers the relative performance of early and late blind and blindfolded sighted people on a variety of spatial tasks, including those related to path integration (Loomis et al., 1993) and reviews of comparative studies to investigate differences in performance e.g. (Thinus-Blanc and Gaunet, 1997). Although the results of the various experiments carried out do have relevance to spatial abilities, this work does not consider the issues presented in this paper, namely the details of how blind people form mental maps and recognise objects and the implications for designing ETAs. Giudice (2018) provides a useful summary of work in this area and suggests that the main areas where blind people experience difficulties are in making inferences due to the lack of information which is accessible to them. He makes some suggestions for ETA development, but they are fewer than those presented here and less directly related to supporting mental modelling. Unlike this paper, he does not consider how blind people use sensory information to identify object and develop mental maps.

There is also limited work on applying knowledge of the spatial understanding and representations of blind people to the design of travel aids. (Guerreiro et al., 2017) consider the ability of blind people to construct sequential environmental representations. Giudice et al. (2021) consider the types of information that blind people require to support safe travel and their design approach involves the user actively engaging with the system to receive navigation instructions.. Guerreiro et al., (2018) investigate user behaviour during indoor navigation and use their results to make recommendations for the development of navigation devices. Ahmetovic et al. (2019) carried out a user study on two routes to investigate the types of instructions and contextual information required to support travel based on familiarity and use of a long cane or guide dog. They also identified the need for personalisation options. However, none of these papers come close to the detailed and novel suggestions for future travel aids and travel aid functions and features presented here, as well as the guidelines for designing travel aids.

3. Methods

Ethical approval was obtained from the ethics committee of the University of Glasgow College of Science and Engineering. The information and consent sheets were translated

into Portuguese and sent electronically to all participants as the most accessible way of providing them information. Participants were recruited from one of the researchers' contacts.
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3.1 Experimental procedures

The experimental work involved two outdoor routes with very different characters, on the grounds of the Foundation for Special Education of Santa Catarina (internal route) and on roads near it, ending at the Foundation (external route). They will be described in detail in the following subsection. There were three main components for each route: (i) walking along the route and providing commentary; (ii) describing the route immediately after the experiment; and (iii) answering questions about the route and basic demographic information. For each route this lasted approximately an hour to an hour and a half. Before starting to walk along the route participants were given more detailed information on the experimental procedures and given the opportunity to ask questions about both the research and the experimental procedures. This took place inside one of the Foundation buildings. Participants were given the choice of being collected and driven to the Foundation and driven back again or making their own way there.

Each route was followed by one participant at a time using a long cane or electronic cane. On the internal route they were initially guided round the route and then completed it on their own. This was not possible on the external route due to its greater length and the fact that participants and researchers had to walk to the start of the route from the Foundation.

Participant safety during the experiments was given the highest priority. On the external route this was achieved by the presence of an orientation and mobility instructor who was responsible solely for ensuring participant safety. The internal route had less traffic and was generally safer and therefore did not require the presence of an orientation and mobility instructor. Instead, participants familiarised themselves with the route by walking round it accompanied before the experiment and the two or three researchers accompanying the participant on the route also paid attention to their safety, for instance alerting them to overhanging bananas on the last part of the route.

Since the presence of an orientation and mobility instructor was required for the external route, participants could only do the external route when the instructor was available. So participants were generally assigned the external route when the instructor was available and the internal route otherwise. Another factor was trying to ensure that approximately equal numbers of participants did each route.

Participants walked without guidance on the first part of the external route and the whole of the internal route. They were given the choice of whether or not to be guided on the second part of the external route which was alongside a main road.

One of the researchers walked in front with a video camera to film the participant. As well as being filmed, everything the participant said was recorded on a digital audio recorder by a researcher walking next to the participant. The participant commented on the route, obstacles and landmarks they were passing and the road surface. The researchers sometimes asked participants how they were able to identify objects, slopes and other features. Prompts of the type ‘Anything else?’ and ‘Can you hear/feel anything?’ were used to encourage participants to comment on everything they were perceiving, particularly when they were quiet for a while. They were phrased neutrally to avoid distorting the results.
The external route ended just inside the entrance to the Foundation campus and the participant and researchers returned to the building participants were initially briefed in for the second and third parts of the experiment and debriefing. After completing the internal

route the participant and researchers sat on a bench outside for the second and third parts of the experiment and debriefing.

The second part of the experiment involved the participant describing the route in their own words. They were asked to do this as if for another blind or partially sighted person with similar vision impairment. The researchers listened without prompting until they had completed the description. They then asked participants if there were any other features of the route they wanted to mention.

The third part was in the form of a brief semi-structured interview. The participant was first asked to comment on their experiences of walking on the route including their sensations. They were then asked follow-up questions arising from their comments. This included questions about how they remembered sensory information and the senses they used to do this. They were also asked their age and a brief history of their visual impairment and what they could see now.

3.2 Descriptions of the two routes

Both routes were outside: the descriptions internal and external relate to the Foundation campus not inside and outside buildings. None of the participants was familiar with the internal route, but only P6 had some familiarity with the external one.

The two routes were chosen to meet the following conditions:

- Within reasonable walking distance of each other, so the experiments involving both routes could be completed in the same session with a break.
- Different characteristics with regard to types of objects and obstacles, traffic levels, road surfaces, smells and other sensory stimuli.
- A variety of different types of obstacles and other objects.
- Significant but not excessive length.
- Pavements on all sections of the route with vehicle traffic.
- Not overcrowded with people, to avoid participants being blocked by them and the recordings of comments being drowned out or otherwise affected by conversation.

The external route (see figures 1 and 2) started at the start of a side road off the main road the Foundation for Special Education was situated on. It ended just inside the entrance of the Foundation and covered a distance of approximately 900 metres. The whole route was on pavements at the side of roads. The route followed three sides of a square on side roads with little traffic; it then turned right onto the main road with heavy traffic on the right, completing the square and continuing downhill to the Foundation entrance. The side roads were approximately on one level and the main road was downhill. There were two road crossings. The first was of the first side road. The second occurred while following the main road and was of a road with minimal if any traffic off the main road. However the presence of a steep slope was a potential source of difficulties. The surfaces of the side road pavements were frequently of poor quality and difficult to walk on. There were also several potentially dangerous obstacles, including rubbish bins, posts and jutting out wire baskets at eye level, a particularly difficult short section of pavement alongside the main road, and a lot of loudly barking dogs on the first side road.

Figure 1. External route schematic representation

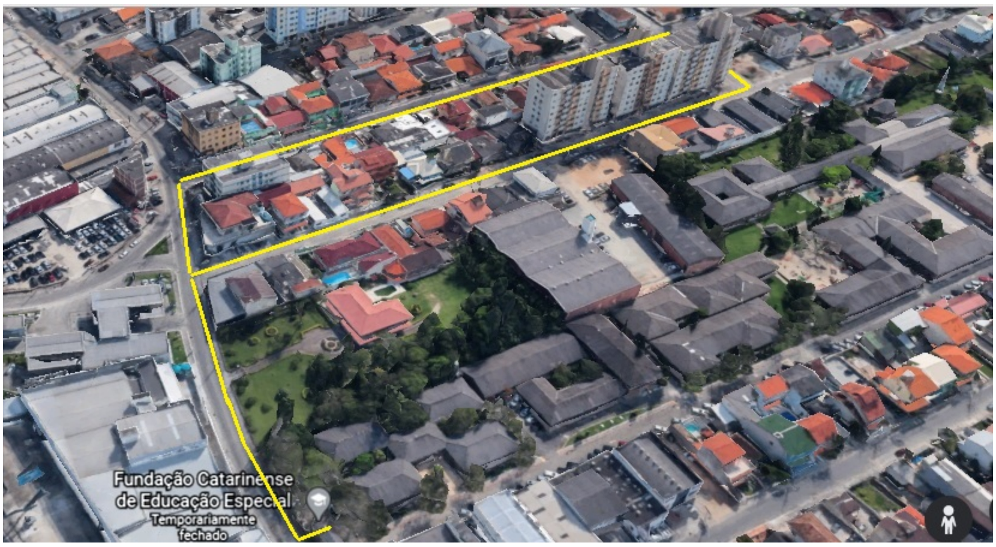

Figure 2. Google earth representation of the external route
Imagery © 2022 CNES Airbus. Maxar Tecnologies, Map data © 2022 Brazil

The internal route (see figures 3 and 4) started outside the Foundations building where participants were briefed at the start. This was on a quiet road with very little traffic through the Foundation campus. There were buildings where classes took place on the left side with several noisy air conditioners on their walls. The route followed the pavement on this quiet road until the first corner. Here it turned left to follow a path along one of the long straight sides of the oval grass playing field on its right with buildings on the left. The route then veered slightly to the right and followed the curve at one end of the oval field to the start of the other long straight side where it veered slightly to the left and had trees on its left hand side. It turned left to follow a narrow path through the trees and then almost immediately left again to pass between banana trees on both sides. Loud music could be heard on this part of the route. The route ended when the path exited from the banana trees. The buildings at the side of the route were mainly used for classes for children and young people. There were several grates or drains on the ground on the path through the banana grove and hanging leaves and bunches of unripe bananas. The pavement and path surfaces were generally of good quality and several sections had tactile tiles. However, there was a ramp up and down at the start and several changes of level. The route ended when the path exited from the banana trees. It was approximately 300 metres in length.

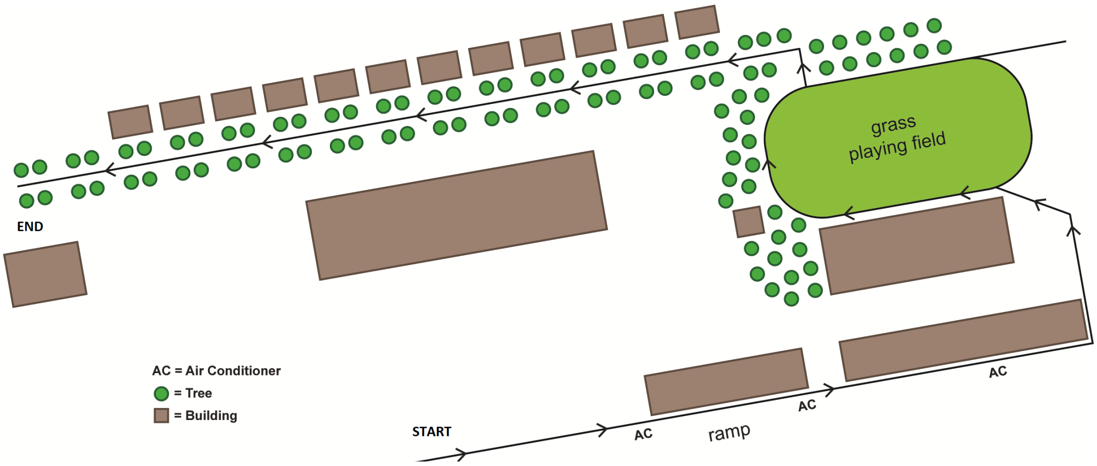

Figure 3. Internal route

Figure 4. Google earth representation of the internal route
Imagery © 2022 CNES Airbus. Maxar Tecnologies, Map data © 2022 Brazil

3.3 Analysis

The recorded data comprised the following, with the numerical order corresponding to the order in which the data was collected:

1. Route commentary, consisting of participants' observations about the route. This included both comments participants made spontaneously and those made after prompts such as 'Anything more?' and 'What can you hear/feel?'
2. Route descriptions, consisting of participants' brief descriptions of the route as they would describe it to a person with a similar visual impairment. This were recorded immediately after participants had finished walking along and commenting on the route
3. Additional information, including further comments about the route and sensory and other information obtained while walking on it, and how this information was represented and stored mentally. It also included participants' ages, what they could see or whether they were totally blind at the time of the experiment and the history of their visual impairments.

To facilitate analysis three separate files were recorded for each participant for each route. Each file contained one of the types of data listed above for that participant and route. All the recordings were transcribed by a native speaker of Brazilian Portuguese without translation and the analysis was based on these transcriptions. It was only at the stage of inclusion of quotes in the text that they were translated into English, by the first author. The analysis was carried out by the first author and checked by the second author with particular attention to the assignment of items to themes.

The descriptions of the two routes were coded first, with each route description coded separately. This involved the following two stages with the second stage having three main components.

1. Stage 1: identification of each feature or action mentioned by each participant and the number of times it occurred. The results were then tabulated, as the easiest way to represent the data.
2. Stage 2: Identification of the main themes. (i) Since the data was in the form of lists of simple items, this was done by examination of the list for each participant for each route. This was used to draw up a list of themes which covered all the features and action points listed for each participant for each route. (ii) The lists of themes for the different participants were then compared. (iii) During this process it was noted that a number of the items involved location of an object in relation to the participant. The original theme of route features was retained when discussing participant comments and route descriptions, but divided into the two subthemes of objects and locations for tabulation. Though subthemes, they will be treated the same as the themes in discussion of the tables. We found that this worked well and hope it does not cause confusion to readers.

A similar first stage analysis was applied to the route commentary files to that used for the route descriptions. However, the first stage resulted in a very large numbers of items. They were therefore grouped together to give subthemes. An example of this is given in table A2 for the external route. The resulting subthemes for the external and internal routes are presented in tabled A1 and A3 respectively.

An interpretivist thematic approach was applied to the route commentary file (Joffe and Yardley, 2004). This involved moving from a description of the data to emerging themes and analysis, and the broader implications of the data. First-order themes were identified without using a predetermined reference framework to capture the essence of the data (Boyatzis, 1998; Braun and Clark, 2006). They were then reorganised into groups via second-order coding and finally led to the two high level themes of object identification and mental mapping.

The next stage involved separate analysis of each of the high level themes. This analysis was carried out on both the route commentary and additional comments data, as possible sources of useful information about these two themes, though the themes themselves were identified by analysis of the route commentary data. The research aims, as indicated in the research questions, were to understand better how blind people represent space, including the senses they used and the types of information they represented. Therefore, the route description data was not included in this analysis, as it is purely involved descriptions of the route without comments on the process of mental map development and the senses involved. In addition, the additional comments data was obtained after the route descriptions so that the participants' mental maps were at least as advanced as in the descriptions.

Coding of the object identification theme resulted in identification of the objects participants had discussed identifying as themes. This resulted in a number of themes for each participant for each route. The themes were then combined across participants and routes to produce a final list of themes including all the objects that participants had discussed identifying with the associated descriptions. An interpretist thematic approach, as described above, was then applied to the coding of the mental map theme.

The final stage of the analysis involved comparison of the information used by the different participants in their route descriptions and mental maps. This involved first obtaining summaries of both types of information for each participant, taking account of the previous analysis. Simple comparisons were then carried out across the two types of information for all participants.

3.4 Participants

There were nine participants, five male and four female, and ranging in age from 30 to 64. They all regularly used a long or electronic cane to support mobility, with four of them using a long cane and five an electronic cane. The length of time for which they had been using a cane varied from nine to 30 years. Five participants (P1, P3, P5, P6 and P9) followed the external route and six the internal one (P2, P3, P4, P7, P8 and P9), with two of them (P3 and P9) doing both. Participant information is summarised in Table 1 with aliases used to maintain anonymity. None of the participants had any knowledge of the internal route and only one participant, P6, had some but not full knowledge of the external route.

Name	Age	Vision now	Age started using cane	Type of cane	Visual history	Comments
P1	37	Totally blind	12	Long	Totally blind from 22, 10% vision at birth, gradual vision loss	
P2	38	Shapes, shadows	19	Elec-tronic	Progressive vision loss	
P3	38	Shapes, light, strong colours	30	Long	Lost sight at age 3	
P4	27	Shapes, colours, reads with magnifier or telescope	18	Elec-tronic	Progressive, 5-10% vision until age 13/14	Sees better at night or when cloudy, uses visual memories to try to understand area
P5	57	Light on/off, bright or dull	27	Elec-tronic	Sighted until age 7 – illness	Mainly rural visual memories, light perception limited help e.g. darker when enters bus shelter
P6	35	Lights on/off light or dark	17	Long	Always poor vision, blind at age 9	Uses street lights as shore line at night, remembers what has seen, but limited
P7	46	Totally blind	24	Elec-tronic	Sighted until age 19	Good sense of buildings and geometry from work
P8	64	Totally blind	47	Elec-tronic	Previously sighted	
P9	30	Strong colour and shapes with right eye	20	Long	About 3% early vision - able to read and write print until 26, blind in left eye at 26	Sees better when cloudy, able use v. large objects and objects with strong colours as landmarks, sees nothing when bright

Table 1. Participant information

4 Results 1: Route Descriptions

4.1 External Route (Route 1)

Three of the participants started their descriptions either from inside the Foundation building or the main road outside it rather than the official starting point at the start of a side road off this main road. This part of the description will not be included in the analysis which will start from the official starting point. The participants all seemed to remember the route well, though P3 did not mention some of the side roads. Participants' descriptions were very varied in lengths and features.

The components were fit into the following four themes:

- Directions/actions e.g. turn left or right or walk one block.
- Characteristics of the surface such as slopes up or down
- Descriptions or features of the route, which were often either landmarks or obstacles e.g. pole, dogs barking, waste bins and narrow pavement.
- Warnings and expressions of concern. This could be general e.g. be careful here or more specific e.g. be careful not to bump into the high level waste bin.

The section is divided into five subsections. The first section 4.1.1 provides an overview of participant descriptions and some illustrative examples from them. Section 4.1.2 discusses some specific features in participant descriptions such as road crossings. Section 4.1.3 provides an overview of the themes in the participant descriptions and section 4.1.4 discusses the themes of location, warnings, and surface and path features. The final section 4.1.5 considers differences and similarities between participant descriptions.

4.1.1 Participant Descriptions: Overview and Illustrative Examples

P1's description was the longest and most detailed. P3's description was the shortest and less complete than those of the other participants, as it only included the first road and the main road and missed out two of the side roads. P1 included a large number of descriptions and features as well as a much smaller number of directions/actions and a few indications of the need to take care. P3 and P5 focused on directions/actions, P6 landmarks and warning about the need to take care and P9 obstacles to avoid and directions/actions with route features mainly presented as obstacles or dangers to be avoided.

P1 started with 'you soon note it is quite an uneven pavement' and mentioned unevenness, slopes and changes in level several times, for instance 'the pavement was quite uneven' and 'you turn to the left there, there are also some differences in height and some higher steps.' P5 started by commenting that 'there were not a lot of problems it was not very complicated'. P6 started with a warning of the need to take 'a lot of care. The pavement is very rough but the first part is worse than the second.' Further warnings included 'You need to pay a lot of attention to check that cars are not coming in or going out',

P3's description was divided into three segments, the first and third about the two roads and the second the road crossing with an additional comment that 'the pavement on all these roads is not good'. P5 provided a brief description of the movement along the route. 'We were walking straight we crossed a road then we turned right then left and we went round the square on the way back we crossed the road again and were returning here'. This was followed by the further comment that the route was 'not so difficult' and mention of 'some obstacles, lampposts in the middle of the path'. She required prompting to provide further information.

A typical section of P1’s description was as follows: 'Afterwards we followed the part where I had come on Marcelo's arm. Coming and going I was using my cane and identifying ... there was tactile paving on practically all this part. We passed various things like different walls and most of them had gratings, birds singing and we also passed the bus stop, which I was able to identify immediately on the way there but not on the way back ... but I was a bit more certain when I was almost leaving it.' Each segment of P3’s description included a description of the road or crossing. The crossing description was as follows: ‘We crossed the road. I felt calm when crossing as you could hear the traffic from both sides. The road was quiet, there was not a lot of noise. On the other side the road was cleaner. It had a tactile pavement so it was easy other than that very steep descent.’

Tables 2a - e summarise participants’ descriptions of the external route with items organised by the three themes and two subthemes. There is considerable variation between participants in both the items referred to and the number of items mentioned under each theme.

	P1	P3	P5	P6	P9	Total
Continue straight/on	5	2	2	1		10
Cross above ditch					1	1
Cross road	5	1	1		2	9
Follow/go round (with cane)	1		1		2	4
Go to end			2		2	4
Return			2	1	2	5
Right/left a bit or continue to right/left	3		1			4
Turn right or left	3		4	1	1	9
Walk block or part of one					3	3
Total	17	3	13	3	13	49

Table 2a Summary of directions in participants' descriptions of external route

	P1	P3	P5	P6	P9	Total
Corner	5		1		1	7
End/other side of road		3			1	4
First/second/middle road				3		3
Foundation	2	1			1	4
In front of		2			3	5
Main road	1			1		2
Middle of path			1			1
On right/left	2	1			1	4
Total	10	7	2	4	7	30

Table 2b Summary of locations in participants' descriptions of external route

	P1	P3	P5	P6	P9	Total
Degree of difficulty			2	1	1	4
Heavy/low traffic	2	1				3
Narrow/wide pavement, wider/narrower	5				1	6
Parallel roads				1		1
Quality of pavement/route	2	3		3	2	10
Quiet/noisy		1		1		2
Slopes up or down	5	2		4	1	12
Tactile paving (absent or present)	2			1	3	6
Traffic in one or both directions	1			1		2
Unaligned pavement					1	1
Total	17	7	2	12	9	47

Table 2c Summary of surface or road features in participants' descriptions of external route

	P1	P3	P5	P6	P9	Total
Birds	2					2
Bus stop	1				1	2
Cars	3					3
Cars/other sounds easy to hear		4				4
Entry/gate	3			1		4
Grating	4					4
Gutter	2					2
House (high)				1		1
Open/closed and other spaces		3		1		4
Smell	1					1
Speed bump				1		1
Trees	1					1
Wall (high)	1	1		1	2	5
Total	18	8	0	5	3	34

Table 2d Summary of objects in participants' descriptions of external route

	P1	P3	P5	P6	P9	Total
Avoid edge/corner					1	1
Cars moving in and out				1		1
Ditch (large)					1	1
Dogs	5				1	6
Need for care/caution	3	1		2	2	8
No landmark			1		1	2
Post/sign (on pavement)	2		1	1	1	5
Step (high)				1		1
Un/even or ir/regular pavement	6					6
Waste bin at face height	1				2	3
Total	17	1	2	5	9	34

Table 2e Summary of warnings or alerts in participants' descriptions of external route

4.1.2 Specific Features in Participant Descriptions

On prompting P5 provided additional information about the road crossing and the subsequent route. 'I did not find a landmark to say exactly at what point on the road I crossed. I did not check to see if there was a lamppost or other … I know we crossed near the corner, we then turned to the right for a bit … then we turned to the left and followed the road. When we reached the end of the square we turned left again and …' This description had minimal information about features and landmarks and no information or warnings about difficulties to avoid or places to take care. P6 only made one explicit mention of the direction to take. 'To return you need to see clearly where … to turn left by the traffic on the main road. … You go to the left and continue for a bit on the tactile paving and then the surface has a bit of a slope'. He also commented briefly on the 'best part, the quietest part', which was 'in the middle between the two parallel roads.' In this way he indicated indirectly the need to go round three sides of a square. However the subsequent information about turning left did not indicate whether this was to complete the square or go in another direction. The combination of actions and problems in P9's description included 'I crossed the road to the left side and continued for a block until the end, but it was a block in a really bad condition. ... There were several sections of the pavement with a slope ... up and down, up and down.'

Both P1 and P9 provided a detailed description of a difficult road crossing involving detouring round a high step. ' Then I went to the corner, there was a road in front of me, and when I went to cross it there was a valley, a really big section, there was grass and I thought there was water. I was afraid to tread on it, but I did not need to be. With my cane at the other side I passed over it, a step of more or less one metre to cross this valley and reach the return pavement' (P9).

P6 drew attention to the need to pay 'a lot of attention to cars going in and out' and 'the very high step you have to go down but going round a bit to the left there is a slope you can go down.' P9's warnings included: 'You need to be very careful, because right at the start there are two litter bins close together and they are at face height and could really hurt you. After these blessed bins there are dogs, you also need to be careful with them, as they are tied up, but they leap at the fence and frighten you.' P1 provided both explicit and implicit warnings: 'there are dogs so you need to be careful not to put out your hand' and 'it alternates dogs, drains. It is a block with a fairly small pavement in places. ... There is a post in the middle of the tactile paving which P6 knocked his hand on to prevent me bashing my head'.

P1 was the only participant who mentioned a road name in their description, in this case for the main road. She also commented on pavement width: 'it is becoming narrower .. part of it at the end is very narrow, which is where you get to the next corner'. She recognised that they were walking round a square and had returned to the part over which she had been guided at the start 'then we continued on the part I came on Marcelo's arm.' P6 also commented on 'high walls or tall houses' and entrances that could be recognised 'by the slopes/ramps' and 'a lot of slopes/ramps on the first road'. He considered it more important to check his left than his right side and found it easier to turn his head to his left side, probably due to differences in his hearing.

4.1.3 Overview of Themes in Participant Descriptions

Table 3a presents the items raised by at least three participants or at least three times and table 3b presents the number of items raised by each participant under each theme and the totals. As table 3a shows, there are items from each theme mentioned by at least three participants and at least three times. Many of the directions were relative to the individual, rather than the landmarks frequently used by sighted people. They included continuing straight/on, and turning right or left (four participants); and return. Others were relative to the road or path, such as crossing the road (four participants); follow/go round with cane (3 participants) and go to end (3+ mentions).

	Number of participants mentioned by		Mentioned 3 – 6 times
	3	4	
Directions	Return Follow/go round (with cane)	Continue straight Cross road Turn right or left	Go to end (4 x)
Location	Corner Foundation On right/left		End/other side of road (4 x) 1st/2nd/middle road (3x) In front of (5 x)
Surface Features	Degree of difficulty Tactile paving (absent/present)	Quality of pavement/route Slopes up or down	Heavy/low traffic (3 x) Narrow/wide pavement (6 x)
Objects		Wall (high)	Cars (3 x) Cars/other sounds (4 x) Entry/gate (4 x) Grating (4 x) Open/closed & other spaces (4 x)
Warnings		Need for care/caution Post/sign (on pavement)	Dogs (6 x) Uneven/irregular pavement (6 x) Waste bin (face height) (3 x)

Table 3a, Summary of the items frequently mentioned for each theme

4.1.4 Discussion of the Themes Location, Warnings and Surface and Path Features

Locations included relational locations such as on right/left (3 participants) and in front of (3+ mentions), locations relative to the pavement or road, such as corner (3 participants) and end/other side of road (3+ mentions) and a specific location, the Foundation (3 participants). Many of the objects mentioned could be used as landmarks. They included (high) walls (4 participants), which, if continuous, could be used as a shore line to enable participants to walk in a straight line, entry/grate and grating (both with 3+ mentions). Other objects mentioned were cars and cars/other sounds (both 3+ mentions), which could act as landmarks in some circumstances.

Warnings included a general warning, need for care/caution (4 participants), most of them related to specific obstacles, such as post/sign on pavement (4 participants) and waste bin at face height (3+ mentions) and specific dangers, such as dogs and uneven/irregular pavement (3+ mentions). As is often the case, objects can be both obstacles or otherwise hazardous and landmarks. Thus, the post sign, dogs and uneven pavement could potentially also be used as landmarks. However, since the waste bin could not be detected with the cane, it was solely a hazard.

Surface and path features included the quality of the pavement or route and slopes up or down (4 participants); the absence or presence of tactile pavements (3 participants); narrow/wide and heavy/low traffic, narrow/wide pavement and open closed and other spaces (3+ mentions). Many of these features could act as landmarks and indicate to participants that they were on the correct route. Several of these items involved the type of surfaces participants were walking on and indicated them paying considerably more attention to them than sighted people generally do.

4.1.5 Differences and Similarities Between Participant Descriptions

Theme	P1	P3	P5	P6	P9	Total
Directions	17	3	13	3	13	49
Location	10	7	2	4	7	30
Surface or path features	17	7	2	12	9	47
Objects	18	8	0	5	3	34
Warnings or alerts	17	1	2	5	9	34
Total	79	26	19	29	41	194

Table 3b, Summary of the number of items for each participant and in total for each theme

Table 3b shows both considerable variation between participants as to the number of items mentioned and considerable differences between them in the distribution between the types of items. The total number ranged from 19 (P5) to 79 (P1), so increasing by a factor of four between the smallest and largest totals. Two other participants, P3 and P6, had totals at the lower end and one, P9, in the middle. P1 had significant numbers of items under all the themes, but lower on location than the other themes. P5 and P9 both had a high number of items under directions, with P5 having very few items for the other themes and P9 moderate numbers other than for objects. P3 and P6 both had their highest values for directions. The items were well distributed between the themes, with more directions and paths features, about 50 of each, than locations, objects and warnings or alerts, about 30 of each.

A summary of the items commented on by the participants while walking on the external route is presented in table A1 in the appendix. This includes both items which were mentioned spontaneously by participants and those mentioned after prompting to see whether they had noticed anything additional. Participants mentioned at least two to five times as many items while travelling and commenting on the route compared to while describing it subsequently. This is not surprising, as route descriptions are a summary of salient features. In addition, the comments while on the route included, for instance, people, birds, machinery and the sun, which were not necessarily permanent features of the route. The items mentioned could generally be organised into the same categories as the route description features.

Many of the comments included both an object or feature and a location or other details of the feature. To give a table of manageable size all the comments about a particular feature or location are included together. An example of the details of the comments made by participants is given in table A2 for the feature 'open'.

4.2 Internal Route

The section is divided into four subsections. Section 4.2.1 discusses the qualitative differences in the route descriptions of the two routes by the two participants who described both of them. Section 4.2.2 and 4.2.3 respectively present an overview of the themes and specific examples of them in participant descriptions. Section 4.2.4 presents an overview of the items mentioned and their distribution between the different themes.

4.2.1 Qualitative Differences in Descriptions of the two Routes

P3 and P9 provided descriptions of both routes. P3's description was again short and P9's long. There were qualitative differences in their descriptions of the two routes. P9's description of the internal route focused on surface textures and sounds which acted as landmarks for continuing or changing direction. She mentioned a few difficulties without warning against them, for instance, part of the route was 'a bit complicated ... as there was nowhere to get support at the sides ... no landmarks, no tactile paving, no real pavement, nothing to orient yourself by ... no references at the sides'. However, it was not difficult once she had 'some idea of the direction'. However, her description of the external route focused on obstacles to avoid and directions/actions.

4.2.2 Overview of the Themes in Participant Descriptions

Tables 4a-e summarise the items participants referred to in their descriptions of the internal route organised by the five different themes. The specific items referred to are very different to those in tables 2 due to the different characters of the two routes, but they are distributed over the same themes. However, there are still significant similarities. There is again a considerable variation, both in the points participants considered significant in the number of items they mentioned from 16 (P3) to 52 (P9). Table 5a contains the items under each theme mentioned by at least three participants or at least three times. Similar further comments could be made as for the external route, so will not be repeated.

	P2	P3	P4	P7	P8	P9	Total
Continue straight/on	3	2	2	1		3	11
Distance or number of steps to walk	1	1				3	5
Enter to the left	2	2					4
Go to/end of pavement/path	4						4
Go to other side of path						1	1
Path curves to right	2					1	3
Path not curve at start					1		1
Turn to left or right	6	1	1	2		2	12
Total	18	6	3	3	1	10	41

Table 4a Summary of directions in participants' descriptions of internal route

	P2	P3	P4	P7	P8	P9	Total
Corner	1			2			3
Empty space				1			1
In front	2			1		1	4
Near, nearer/further away e.g. building				1	1		2
On left/right of pavement/path	2					4	6
Street of foundation		1					1
To left or right - location				3	3	1	7
Where walk on path – middle or edge	1		1		1	1	4
Total	6	1	1	8	5	7	28

Table 4b Summary of locations in participants' descriptions of internal route

	P2	P3	P4	P7	P8	P9	Total
Change in surface	1		1	3		2	7
Grass			1	1		1	3
Line/guide on path			1			1	2
Narrow path						2	2
Ramp to entrance				1			1
Slopes up and/or down	1	1	1	1		1	5
Type of surface e.g. sand, gravel, no holes	3	1	5	5		6	20
Total	5	2	9	11	0	13	40

Table 4c Summary of surface and path features in participants' descriptions of internal route

	P2	P3	P4	P7	P8	P9	Total
Air conditioner/extractor fan			1	1	1	1	4
Banana tree				1		1	2
Building				3			3
Classroom noise						1	1
Detect/recognise with (sound of) cane	2	1					3
Door			1				1
Entrance/opening	1		2		1	2	6
Grate/drain on ground	3	1		1		4	9
Lot of (big) trees	1	1			1	3	6
No trees at one side						1	1
Playing field - reference on right path					1	1	2
Quiet					1		1
Smell	1					3	4
Sound of children/people		1				1	2
Sound closed/open or more open		2	2				4
Wall as reference/to walk straight			1		2		3
Walls at the side		1				1	2
Wind			3		1		4
Total	8	7	10	6	8	19	58

Table 4d Summary of objects in participants' descriptions of internal route

	P2	P3	P4	P7	P8	P9	Total
Avoid another (incorrect) path to right	1					1	2
Difficult find entrance			1				1
Need to take care	7				2		9
No references at sides						1	1
Obstacles on wall and to left	2				2		4
Obstacles low down/on ground					2	1	3
Total	10	0	1	0	6	3	20

Table 4e Summary of warnings in participants' descriptions of internal route

4.2.3 Examples of the Different Themes in Participant Descriptions

P3’s description of the internal route consisted of action points at particular landmarks. They included auditory ones related to open and closed spaces and surface changes, for instance 'when I was no longer able to hear a closed sound as it had become more open I turned left and went straight on until I came to ... gravel on the ground. ... I turned towards my left and went straight more or less until where I could feel there were a lot of trees'. Her description of the exterior route focused on three roads or crossings. The differences in the internal and external routes may have been due to the fact that the external route was largely rectangular, whereas the internal route was not and therefore required more detailed specification of the points at which changes in direction were required, as well as being safer.

The other participants' descriptions also focused on directions and landmarks at which to take action in the form of surface changes, sounds and shorelines, again supporting the supposition of the need for clearly specified landmarks for direction changes on the internal route. Examples of the use of surface textures as landmarks included 'Next in sequence I turned to the left and went a bit further in the area in concrete and next I came into these pebbles. ... from there I continued ahead until ... I came to that grass there and then I turned left' (P7). P9 'continued walking straight on until I left this cement track and came to a narrow road full of pebbles, very very small stones ... And I crossed to the other side. … There was a guide on the pavement which separated this narrow road from a football playing field ... of grass.'

Jaire referred to both surface type and turnings: 'When the pavement ends, you will see that there is a gravel path. You follow this gravel path walking on the left hand side, you turn to the left, but continue on the right hand side of the pavement, you enter on the left, but keep to the right side of the path, because the path turns to the right'. Other surface features such as changes in level, puddles and drains were also noted. For instance P3 'went down a small slope, then went up again'. P9 'was walking along this very narrow road where there were puddles ... they were not deep puddles, as this was a good road without holes, there were some small slopes as it was cement' and 'I came across some drains ... water was flowing out of the last drain I went past'.

P4 used 'auditory information quite a lot', including as landmarks. 'When I go by an air conditioner, or something that produces wind, this type of thing, I pay attention so I can use it as a landmark. So if I need to return to this area afterwards … I have a landmark.' P9 'walked for half a block, turned to the left. There was a very loud air conditioner noise. I continued walking straight on ... there was noise of people on the wall at the right side ... I continued walking straight on, but in front there was the noise of a classroom, children dragging desks, wheelchairs and children talking'. P4 also used changes in the wind to determine when to turn. 'When I need to turn left I know from the wind that the area is more open, I am aware that the wind does not pass through easily and so I know that it is changing direction.'

P4 and P8 used shore lines. P4: 'At first I oriented myself by the wall … I could use as a landmark, so I knew I could walk in a straight line by following it.' P8's stressed the importance of 'a landmark which keeps us in a straight line ... like the centre of the track or a wall' and stated that 'my main references are the walls and the obstacles on them'. He preferred to use walls to the centre of the track. 'The middle of the track ... does not follow the curve ... and then there are landmarks there [the wall] that are not on the middle of the track'. Finding landmarks was particularly important to P4 in a very open environment where he 'look[ed] for a landmark, something to guide us, so I tried to walk near the edge of the path'.

Jaire was the only participant who provided slightly different descriptions for partially sighted and blind people, respectively 'you go straight forward and when you see the corner you turn left' and 'you go to the end of the pavement and turn left as the pavement ends there and afterwards I think there is grass'. Less frequently used sources of information and landmarks included buildings and empty spaces, the sun, turnings and smells. For instance, P7 used buildings and empty spaces as landmarks, 'where I turned left ... on the left there was a building and on the right empty space' and 'where we turned back there was an empty space near by, banana trees and a building on the right'. P8 also used 'the space opening into the football field' to know he was 'on the right path'. P9 used smells to expand on information she already had, for instance 'a field of grass which by the smell was cut recently' and 'it was full of trees ... by the smell there must have been banana trees very near, as there was a strong smell of bananas'.

There were some warnings of obstacles and to take care, but less of a focus on warnings than on the external route, due to the greater safety of the internal route. For instance, P8 drew attention to the need to 'be aware of the obstacles on the wall' and warned of the 'need to take care with the air conditioners on the walls and the flower pots'. Jaire warned to 'be careful as there are some obstacles on the wall on the left side, be careful so you do not get hurt' and to not get lost 'if you turn to the left, you could possibly find another path and possibly get lost'. There was also mention of a few difficulties, for instance in detecting the entrance to the banana grove, which P4 resolved by finding a landmark. 'It was more complicated to find the entrance that goes from here to the little track. The only landmark I saw was a small slope, I was in the area and there was an entrance.' Renaldo 'located' the 'last entrance on the left' by using 'vegetation ... large trees, a lot of trees'.

The descriptions provided indications of spatial awareness and included some deductions. For instance P3: 'from the noise of my cane on the ground there were walls at the side.' Both P7 and P8 noted that all the turnings were in the same direction. 'On this route everything is on the left.' He also deduced the presence of entrances from the presence of raised areas. 'The concrete surface has some raised areas, I think they are the entrance and exit from a ramp.'

4.2.4 Overview of Items Mentioned and Their Distribution between the Themes

Type of Item	Number of participants mentioned by			Mentioned 3-9 – times
	3	4	5	
Directions			Continue straight Turn left or right	Enter to left (4 x) Go to end of path/pavement (4 x) Path curves to right (3 x)
Location	In front To left or right	Where walk on path – middle or edge		Corner (3 x) On left/right of pavement/path (6 x)
Surface & route features		Change in surface	Slope up or down Type of surface	Grass (3 x) Sound closed, open or more open (4 x)
Objects		Air conditioner Entrance/opening Grate/drain on ground Lot of (big) trees Wall		Building (3 x) Detect with cane sound (3 x) Smell (4 x) Wind (4 x)
Warnings	Obstacle			Need to take care

	locations			(9 x)

Table 5a Summary of the main types of items frequently mentioned

As on the external route, none of the items are mentioned by all participants. The items mentioned by at least three participants or at least three times can again be categorised as directions, locations, surface or path features, objects (which could be landmarks or obstacles) and warnings. However, warnings were less frequently given, with the main one being the need to take care (4 participants). Comments on the surface related to the type of surface (5 participants) and changes in it (4 participants), with the frequent changes acting as useful landmarks, rather than being potentially dangerous features as on the external route. Other route features included grass and the character of the sound (3+ mentions). The internal route was generally safer than the external one, with the main potential problem being the overhanging clusters of bananas, leading to fewer warnings. However, obstacle locations were mentioned by three participants and the need to take care at least three times.

A number of objects found on the route and which could act as landmarks, namely air conditioner, entrance/opening, grate/drain, big trees and wall, were mentioned by four participants. Locations were again relative to objects i.e. in front and to left or right (3 participants) or the path – where walk on it (5 participants) and on left/right of path (3+ mentions). Directions were either relative to the participant e.g. continue straight and turn left or right (5 participants) or to path features e.g. enter to left and go to end of path/pavement (3+ mentions)

Theme	P2	P3	P4	P7	P8	P9	Total
Directions	18	6	3	3	1	10	41
Location	6	1	1	8	5	7	28
Surface features	5	2	9	11	0	13	40
Objects	8	7	10	6	8	19	58
Warnings or alerts	10	0	1	0	6	3	20
Total	47	16	24	28	20	52	187

Table 5b, Summary of the number of items for each participant and in total for each theme

The total number of items mentioned by participants varied from 16 (P3) to 52 (P9), with P2 having 47 and the other participants values in the 20s. The distributions of items between the themes also varied for the different participants. P2 accounted for half the 20 warnings and had a high value for directions. P4, P7 and P9 had moderate to high values for surface features and P9 also for directions and a very high value for objects. There was more variation in the totals for each theme than for the external route, from 20 warnings to 58 objects.

A summary of the items commented on by the participants while walking on the internal route is presented in table A3 in the Appendix. Analogous comments can be made about this table to those about table A1 and will therefore not be presented.

4.3 Comparison of the two route descriptions

This section will provide a brief comparative discussion of the descriptions of the two routes. Both routes have the same five high level themes: directions; location; surface or path features; objects and warnings. The two descriptions have both common and distinct features.

A summary of common elements in the themes across the two routes is presented in table 4a and distinct elements in table 4b. This shows that there are both a number of common elements, but considerably more distinct features. Many of the common features are directions of the type go straight or turn left/right and locations such as on right/left or in front and surface features such as slopes up/down which could be expected to be found in most route descriptions. The differences are frequently feature specific to one or other of the routes which provide more details about the routes and therefore illustrate their differences. They include objects such as air conditioners and lot of big trees, surface features such as tactile pavement and warnings such as post/sign on pavement. For some reason these differences are particularly numerous in the 3+ mentions category, though by no means lacking in mentions by three or 4/5 participants.

Theme	3 participants mentioned	4/5 participants mentioned	3+ mentions	3 participants or 3+ mentions
Directions		Continue straight Turn left/right	Go to end (path/pavement)	
Location	On right/left			Corner In front Open/closed sound/space
Surface or path features		Slopes up/down		
Objects		Wall		
Warnings		Need for care, Caution		

Table 6a Common elements in the different themes in the two routes

Theme	3 participants mentioned	4/5 participants mentioned	3+ mentions
Directions	Return Follow/go round with cane	Cross road	Enter to left Path curves to right
Location	Foundation	Where walk on path	End/other side of road 1st/2nd/middle road On left/right of pavement/path
Surface or path features	Degree of difficulty Tactile pavement (a bsent/present)	Quality of pavement/route Type of surface	Grass Heavy/low traffic Narrow/wide pavement
Objects		Air conditioner Entrance/opening Gate/drain on ground Lot of (big) trees	Building Cars Cars/other sounds Detect with cane sound Entry/gate Grating Smell Wind
Warning	Degree of difficulty	Post/sign (on pavement)	Dogs Uneven/irregular pavement Waste bin (face height)

Table 6b Distinct elements in the different themes in the two routes

Table 6c summarises the total number of items in each theme and the numbers mentioned by the two participants who did both routes. Although the external route was three times the length of the internal one, the total number of times mentioned was only slightly greater (194 compared to 187). On the external route the number of items mentioned by each participant varied from 19 for P5 to 79 for P1 with mean 38.4 and standard deviation 21.5. On the internal route the variation was from 16 for P3 to 52 for P9 with mean 31.3 and standard deviation 13.5. The greater values for the external than internal route are consistent with it being longer and more complex. However, the result is not statistically significant, with p=0.28 for a one-tailed t-test. While worth testing for, the lack of significance was to be expected due to the small sample sizes. Two participants, P3 and P9, did both routes. P3 mentioned 26 items for the external route and 16 for the internal route, whereas P9 mentioned 47 for the external route and 52 for the internal route. Thus, P3's results were in line with finding the external route more complex, whereas P9's were not. However, in both cases P3 identified a relatively small number of items and P9 a relatively large number, indicating consistent behaviour for these two participants across the two routes.

The distribution of items amongst the themes was very different for the two routes. The external route had 70% more warnings (34 compared with 20), indicating that participants found the external route more difficult and risky than the internal one. However, the internal route had 70% more objects (58 compared to 34) than the external one. This may indicated that this route had more landmarks and features. Table also contains data from P3 and P9 as the two participants who took part on both routes. Some of P9's results are in line with and strengthen the trends in the totals, with three times as many warnings on the external compared to the internal route and six times as many objects on the internal compared to the external one. However, in total P9 mentioned more items on the internal compared to the external route (52 compared to 41). P3 mentioned over 60% more items on the external than the internal route, with the greatest differences for location and surface features, but mentioned twice as many directions on the internal compared to the external route. This illustrates the differences between the experiences and perceptions of different participants. However, it is not possible to generalise from this, as only two participants did both routes.

Theme	P3 external	P3 internal	P9 external	P9 internal	Total external	Total internal
Directions	3	6	13	10	49	41
Location	7	1	7	7	30	28
Surface or path features	7	2	9	13	47	40
Objects	8	7	3	19	34	58
Warnings or alerts	1	0	9	3	34	20
Total	26	16	41	52	194	187

Table 6c Items mentioned under the different themes for the external and internal routes

5 Results 2: Object Identification and Mental Maps

5.1 Object identification

The strategies used are summarised in table 2 and then discussed in more detail

Object	Sound	Deduction	Cane	Tactile	Light	Smell	Comments
Access to passage/corridor	X	X					Ramp, sound of people entering and leaving
Air conditioner	X						Characteristic sound
Area becoming more open	X				X		Increased wind, greater clarity, voice broadcast more,
Banana tree	X			X		X	Strong smell of bananas, noise of leaves
Bus stop	X	X	X	X			Sound closing, feeling something above, cane touch bench
Closed area	X		X				Sound muffled, more compact, no echo from cane
Curve	X	X					Sound of person starting walking on it
Door		X	X				As ramp plus wooden surface, sound from people inside
Drain and grate	X		X				Sound of walking over, cane, changing
High wall	X		X				Sound and air noise muffled, less wind
Leaves	X		X				Sound when walking over or of cane
Main road	X				X		Car noise, more open from sound, more light in front
Open area							Sound expands, spreads more, echo from cane
Pavement narrow or widening	X						Sensation in ear, kinaesthetic sensation
Pavement surface	X		X	X			Friction of cane and feet, cane sound and vibration
Post	X				X		Slightly muffled sound of tapping cane
Slopes			X				Cane, feet, feeling body descend
Tactile paving				X			Smoother, red border
Tree	X	X			X	X	Rain falling, birds singing, less light, purer air
Turning to the right	X	X					Sound of person in front moving to the right
Uneven or irregular surface			X	X			Part foot higher, lower or to side

Table 7. Summary of object identification approaches

The participants mainly used a combination of tactile and auditory information to identify a range of different objects and understand their environments better. They also used smells and perceptions of body position and movement to a lesser extent. Auditory information was obtained from the cane as well as directly from the environment. Tactile information was obtained through both the cane and the feet and to a lesser extent through the hands.

In some cases the identification process was very similar to that of sighted people, but based on a characteristic sound rather than a characteristic appearance. For instance, air conditioners were identified by their characteristic sound. In other cases the approach was more complex and required deduction, though this may have become automated over time. For instance, several participants deduced the presence of a door from the available audio and tactile information. P8 deduced it from the presence of a 'ramp' with people 'entering and exiting', indicating 'access to a passage or corridor'; and tapping with the cane indicated a wooden surface. P2 was able to use the 'sound from which there are people inside' and the fact that 'sound spreads differently when there is a wall and when there is an empty space'.

Participants were able to use differences in the quality and features of the sound to distinguish between open and closed environments. In open environments 'the sound spreads more' (P4) and 'expands' (P5) and there was 'an echo' when tapping the cane (P3) and a feeling of 'emptiness' (P7). In a closed environment 'sound does not spread with the same amplitude ... it seems muffled as it is near something' (P2) ,
and the sound was 'more compact, like inside a space' (P5). An area becoming more open was recognised by 'increased wind', 'greater clarity' and 'your voice being more widely broadcast' (P3) and 'the sound opening' and 'no air blockage as there is nearby a wall' (P2). A (high) wall cut out sound and 'air noise is muffled, the wind does not pass as in an open space, the sound of the cane seems nearer' (P3) and 'the sound of the cane is more blocked than on the other side' (P2). A post was also detected by a 'slightly muffled sound' when tapping the cane (P3), a feeling the environment was 'closing' (P6) and its shape (P2).

A main road was distinguished by 'car noise' and being 'more open from the sound' (P3), 'cars passing' (P6) and 'more light in front' and 'no sound of the wind in the leaves in front' (P2). P6 was able to estimate the distance to the road from the sound. Similarly sound quality and changes could be used to determine when the pavement was narrow or became wider. A narrow pavement was identified by a 'kinaesthetic sensation ... more a sensation than auditory ... muffling as if closing' (P1). Other objects indicated by 'the sound closing' included bus stops (P5) which were also identified by 'feeling something above, touching the bench with the cane' (P9).

Some objects were identified indirectly through the presence of other objects or a particular ambience. For instance, trees were identified by a variety of senses and types of information. This included 'the sound of the rain falling' (P5), 'purer air underneath it ... open space, the sun does not get in and the light is blocked, birds' (P6), 'birds singing' (P9), 'smell, wind striking the leaves' (P8) and 'contrast with the dark ground, sound of wind in the leaves, birds' (P2). Banana trees were recognised by 'the strong smell of bananas' (P9), 'with the hand' and 'by the noise of the leaves, seeing the leaves shake' (P2)

Types of surface and changes in them were determined largely though touch, of the foot and/or cane. Slopes were identified through touch, proprioception and kinaesthetics. Different surfaces, such as fine and course gravel, could be distinguished by 'the sound and the friction of the shoes with the ground and the ease of movement ... softer, more comfortable ... coarser gravel ... like fingers under the feet' (P2). In the case of gravel and concrete 'the sound and vibration of the cane in the hand are different' (P2). Cement was identified by 'friction of the cane and the sensations of the feet when walking' (P2). . Slopes were identified by the feet or cane and down slopes by the cane or 'feeling your body descend' (P3), the cane and feet (P1) and 'speed of walking' (P2). Uneven surfaces were identified by feeling that 'half the foot is higher, half lower' (P2) and changes in level by the 'cane' (P8). A level, but irregular surface was identified by 'the touch of the cane ... sometimes you feel half the foot is higher, lower or more to one side or the other' (P2). Tactile paving could be detected with the feet (P3) and was 'smoother' and had a 'red border' (P9).

However, objects on the ground were often identified by sound. For instance, leaves were identified by the sound when walking over them (P3) or the sound of the cane (P3 and P7). Drains and grates were recognised by the sound of the cane (P3, P5, P6), 'the sound when walking over it' and 'the sound of the cane changing' (P3). Awareness of the movement of other people could also be a useful source of information. For instance, P2 recognised a curve from the sound of 'another person starting to follow the curve' and the need to turn to the right from the 'sound of a person in front moving to the right' (P2). Awareness of wind and changes in this awareness were further sources of information.

Participants were sometimes aware of the presence of an object without being able to identify exactly what it was. A 'characteristic sound' was used to recognise a motor or something similar, 'different sounds' for metal and other things and 'a different cane sound' for an object at the side (P3). 'A sensation of heat' (P3) and 'before touching it ... feeling it organically' were used to detect a vehicle or other large object with the detection distance larger for a larger object (P1).

Participants were able to use previous experiences of particular smells and sounds to recognise them. For instance, P9 'remember[ed] the smell of banana trees ... So when I smell this smell I recognise it, as I already know it.... When I was a child I lived in a rural area where there were a lot of banana trees in the surroundings ... so I remember this smell. ... Now when I pass under banana trees, when I smell this smell, it seems as though a memory of a banana trees comes into my head from when I was a child.' She was able to recognise sounds including children's voices and birds. 'I have worked with children … I have got nephews, so I can distinguish the voices of adults and children ... Birds as well, from childhood ... from having lived ... on a farm.' P8 was also able to recognise sounds he had heard previously. 'I can only recognise a sound if the sound I am hearing ... is related to a sound that I have heard identified'.

5.2 Mental Maps

The sensory information used in forming mental maps and some other important information about them is summarised in table 8.

	Use term mental map	Mentally draw	Memories of movement	Number visits to learn map	Visual memories in map	Audio memories in map	Tactile memories in map	Smell memories in map	Main component	Impression seeing from map	Experience sensations when describing	Comments
P1	X	X		one	X	X	X	X			tactile	Tactile sensations when describing route, as moved along route remembered it and formed mental map
P3	X				light and shade	X			sounds		audio	Sounds as if hearing them, mentions visualising, but not visual map, not use smells or touch
P4	X	X			X	X	X	X	hearing and touch			Remembers some sounds as images, uses imagination to make tactile map
P5			X			X						Remembers route as if walking on it, sense of space and sound difference in open/closed area
P6												Experience of relief diagrams, mental representation of square not visual or tactile
P7	X			several	X				visual	X		Mental maps gives impression of seeing, particularly when knows area well
P8	X			one	X	X	X	X	visual	X		Mental maps give impression of seeing, particularly when knows area well
P9	X	X			X	X	X	X	memory			Discusses visual and other memories separately, associations for smell and audio memories

Table 8. Summary of information about mental maps

Table 8 contains information from eight of the nine participants. The remaining participant, P2, did not provide information about mental map formation or his sensory experiences when describing the route, so no conclusions can be drawn about his mental representations. Six of these participants used the term ‘mental map’ explicitly. A further participant, P6, used information about movement and direction changes ('we went up one street, turned to the left, we took the next turning on the left again and turned to the left again') to recognise that 'we made a square', indicating he had mental representations of space. His previous experience with relief diagrams helped him with this. 'I always had a lot of contact with relief diagrams, so I am able to imagine ... four lines that join up to form a square ...'. However, he was unsure what senses he was using. 'It's not visual and not tactile. I do not know what it is like ... only that I have a square in my head.' Although P5 did not use the expression mental map, when describing the route she was trying to do so as if walking on it, indicating a mental representation. 'I was trying to repeat the path, … my steps, the succession of things where we went. ... to remember how I was walking ... to do the description, but walking.'

The table further shows the different sensory information used in forming mental maps. The most common was a combination of audio, tactile, olfactory and visual information by P1, Leondro, P8 and P9. However, they used the different types of sensory information in different ways. The main elements of the map were respectively auditory and touch, visual, and memory for P4, P8 and P9, whereas P1 did not indicate what she considered the most important component. P3 used sounds as the main source of information and experienced auditory sensations when describing the route 'as if I were hearing'. She combined this with information about light and shade. The remaining participant, P7, had purely visual mental maps which drew on his previous experiences of seeing. 'I was able to see until I was 19. I associate [in the map] as if I was seeing'. P1 noted the role of vision in mental maps for blind people with previous visual experience: 'clearly, this is a concept, which does not need to be developed visually, but my first lessons in crossing the road were visual. So naturally this is what comes to my mind.'

P1, P4 and P9 felt they were mentally 'drawing' the map and P1 and P9 both used movement in developing their maps. P1 used movement along a route to learn it and form a mental map. 'As I was moving along I was learning the route and developing ... my mental map in my mind. She felt as though she was 'drawing' the mental map 'as I was doing the route'. P9 related her mental map to awareness of walking along the route. She made 'a mental map as if it were a drawing of the route ... a schematic diagram. For example, if you tell me I will walk two blocks to the right and turn to the left, this is the drawing I will make in my head, as if I were walking these two blocks and then turning to the left'. P4 spoke of 'the construction of a mental map which I am drawing in my head'.

P9 and P1 had visual maps which also used other sensory information. P9 ‘tr[ied] to make a visual map of what I am going to do and where I am going to go' and P1 was 'forming this … seeing that it [the road] is narrow in my mind. So I am forming it visually.' P9 and P4 both drew on all available information, with P4 noting the particular importance of touch and hearing. 'A bit of everything - hearing, smell, touch. I think we use hearing and touch most to create this type of mental map'. P9 used memories. ‘It is an auditory, smell and tactile memory. I need to include everything to be able to construct this mental map.'

P1’s mental map included ‘images from my experiences of sound and touch‘. She had tactile sensations when describing and remembering the route. 'I have tactile sensations as I am mentally going along the route and remembering that there are down-slopes on the pavement, places where it narrows. ... So I am experiencing them again … and having the same perceptions as when I was doing [the route]'. However, there were also differences. 'Of course it is not the same memory as when I am experiencing it, but remembering and tactile sensations are linked to each other ... also sound and smell ... birds singing, bad smells'. P4’s mental map included tactile elements after he had been using a tactile map. 'In a certain form,... this open map will give me a tactile direction. ... It is basically … a virtualisation of the tactile map.' However, he used 'imagination' to make a mental map of the tactile map. He also used 'images', including '3D models' of auditory stimuli. 'When I have an auditory memory, I sometimes have a sort of image ... as if I was imagining a 3D image in my head'.

P8's mental maps were largely visual and P7’ purely visual, with P8 also experiencing other sensations. He felt 'as if I were seeing, making an image, a map in my mind. ... I imagine a street. … As I am experiencing it through touch, sensations … and I see it in my mind.' He remembered sensations in his mental map, but did not perceive or experience them. 'In my mental map I remember the smell ... I know what it is like, but I am not smelling it when I am remembering the cafe ... as it is not there.’ P7 drew on his memories of sight and landmarks to develop his mental maps. 'I was able to see until I was 19. I associate [in the map] as if I were seeing and went several times to a place and focused on some landmarks ... It's a bit like seeing in a big city where you have not been before. ... There was always a building that stood out or a tree or something. I was marking the area using these landmarks and I think I used them to create my mental map.'

Sounds had the major role in P3's mental map. 'I have something like a mental image of the way, the sensations I felt - sounds ... wind. … in my mind as if it were a map which enables me to visualise the route . ... These noises are a form of mental map … of the route.' Her mention of 'visualis[ing]' refers to auditory sensations and brightness in her mental map. 'In my mind ... as if I was hearing. ... I use sounds a lot to travel … I see brightness in my mind.' She combined auditory information with information about light and shade in her mental map. 'This mixture of shade and light helps me a lot ... an association of the two maps, audio and mental, in my mind'. P3 recognised the value of tactile information. 'Touch is useful ... for some places where I know it goes up and down, but I would need to count the number of slopes up and down.' However, she did not use it in her mental maps. 'Other sensations than audio and brightness in my mind ...no ... possibly because I have got used to using sound and brightness.

Both P5 and P3 obtained spatial information, particularly related to open and closed places and used sound to distinguish between them. 'When the area is open the cane gives an echo when you touch the ground with it. ... When the area is closed you do not hear this echo' (P3). She used some spatial information in her mental maps, 'the path in my mind with these sensations, with the spaces that are more open'. While walking P5 experienced sensations related to the type of area. 'The sensations were mostly spatial, perceptions of which places had walls, which places were open ... areas without buildings ... very closed ... some concrete walls, but not very high'. She obtained this information through sound. 'On account of the sound. ... when it is more closed the sound is more compacted, and when the area is open and there is nothing near the sound expands and spreads … the cane gives an echo when you touch the ground with it. ... When the area is closed you do not hear this echo.' However, she did not does use this sensory information in her mental representations.

Both P1 and P8 needed to do a route only once to produce a mental map. 'And when I had finished it and got back to the initial point I had managed to form the whole map.' (P1). P8 'remember[ed] exactly. So, as I do the route once, I make a mental map of it'. However, P7 used repeated visits to create a mental map. 'I form a mental map … through going to a place several times.' P8 was particularly confident of the accuracy of his mental maps 'and I do not make a mistake'. However, P4, P1 and P9 felt theirs differed from reality. P4 considered 'it is a sort of creation, as I know I will not have knowledge of the whole space ... As I have an idea of the environment, I am able to create something which is a bit fantastical ... something created in my head'. However, P4 was able to use his mental map 'so I can remember that moment'. P9 felt her mental maps differed from reality due to using her 'rather limited previous visual experiences'. P1 considered her mental map was 'not so close to what you [sighted people] are seeing.'

P7 and P8 were able to use their mental maps to give an impression of seeing the area, particularly for areas they knew well. P8 knew 'every centimetre of my house. I do not use a cane ... I run up and down the stairs. ... At times ... my mental map is so clear that I have the impression I am seeing'. For P7 describing a route he knew well was like visualising it, even though he had not seen it previously. 'It is as if I am seeing and describing a visual map. ... I did not go there when I was sighted. But after going there often and ... several times … with sighted people who described things.' P9 used her limited vision and experience of vision to imagine herself walking along the route. 'As I am able to see a very little bit I can imagine this path as if I were walking on it . ... On a route I already know I am able to imagine it as I remember it. ... I remember myself walking on it as I know it.' Her visual memories gave her the impression of seeing. 'I remember a visual image as if I were seeing. ... as if it were a visual memory.'

Several participants were able to use their mental maps in support travel. P3 was able to make deductions about her environment and the appropriate actions. 'I am hearing the sound of children here and I see the light is a bit stronger here so there is an entrance and I can go in.' 'Where I hear cars I know there is a road at my side and ... I can cross'. P1 used existing knowledge and experience to help her find her way on unfamiliar routes. 'It was a new route. ... I had experience of walking on the road, experience of using the cane, experience of a route I did not know and needing to walk more slowly. So with this previous knowledge I walked the route. I did not need to know every detail to go along it with my cane.' P9 used her memories to remember and presumably retrace a path and also describe it. 'Remembering means being able to describe for another person. ... being able to remember the path I took. ... It is alive in my memory.' P4 was able to use 3D images to help him locate objects. 'I have a habit of creating a sort of 3D model in my head to help me find things.'

6. Discussion of the Responses to the Three Research Questions

This paper is based on an analysis of the features noted by a group of nine blind people while walking on two routes of very different characters and their subsequent descriptions of and comments on these routes. This was used to answer the following three research questions:

1. How do blind people identify environmental features while travelling and what sensory modalities do they use to do this?
2. How do blind people use sensory, route and other environmental information to form spatial representations and what sensory modalities are used in these representations?
3. What are the implications of the responses for the design of travel aids to better support the development of mental models of space?

Although a relatively small group, participants had a range of ages from 27 to 57, and diversity in their current visual status and visual history. Current visual status ranged from being able to see colours and shapes and read with a magnifier or telescope to total blindness without even light perception. They were approximately (male-female) gender balanced.

There is a body of work, discussed briefly in the introduction and literature review, on blind people's mental maps and the use of tactile and audio tactile maps to support mental mapping. However, there is minimal if any work on their relationship to route and other environmental information and the identification of environmental features. In addition, considerable further work is required on the effective use of the spatial processing of blind people to improve the design of travel aids.

6.1 Identification of Environmental Features

The results show that blind people are able to identify a wide range of environmental features while travelling. They use a combination of their different senses, knowledge based on previous experience and associations and reasoning to do this. Auditory and tactile sensations, including from the cane, were the most commonly used, with a slightly greater use of sound than touch. Some objects, such as air conditioners, had a characteristic sound, making them easier to identify. Scents and light were also used, but infrequently. Deduction was sometimes used to identify the presence of a particular object from that of other objects, animals or sensations. For instance, a tree was identified in various ways, including, the sound of rain falling, birds singing, and the smell and wind striking the leaves. Contact with the feet or cane could be used to identify different types of pavement materials and slopes could be identified by the feet, cane or awareness of feet or body position and movement.

6.2 Relationship between information used in route descriptions and mental maps

Table 9 presents an overview of the use of information in directions and mental maps by the different participants. Participants used different combinations of sensory information in their mental maps, but one or two senses generally had the main role. Movement also had a role. P1, P5, P9 and possibly P6 used movement to form the map or remember the route as though walking along it.

The relationship between the route description and mental model is clearer for some participants than others. Sounds were the main component of P3's mental maps and they were also important in her route descriptions. She used open/closed spaces (generally determined by sound) in her mental map and also in her route description. The main elements of P4's mental maps were tactile and auditory, and of his route descriptions auditory with tactile information also used. He also used visual and olfactory information in his mental maps. P7 had a purely visual mental map which drew on his memories of seeing and P8 a largely visual one which also used touch, sound and smell. In his route description P7 located objects relative to himself and his landmarks included buildings, empty spaces and the type of surface.

P1, P4 and P9, felt they were drawing their mental maps in their heads. However, hearing and touch provided the main components of P4's mental map, rather than vision and P9's was based on audio, tactile and olfactory as well as visual memories. In their mental maps P5 remembered the route as though walking on it and P9 imagined walking on the route. P5's route description was based on movement and direction changes. P6 used movement and direction changes, as well as experience of using tactile maps, to produce mental maps which were neither visual nor tactile. His route descriptions used a combination of audio and tactile information.

The following inferences can be drawn from this discussion, though research involving a larger sample will be required to confirm them:

1. Blind people are capable of a good spatial understanding which can be used to provide route descriptions and mental maps.
2. Blind people use all their available senses to different extents and in different combinations in their spatial representations, with a particular sense sometimes having

the main role. In line with the literature (Hersh, 2020a, Kulyukin et al., 2008), tactile and auditory information are particularly important for blind people.

3. Some blind people draw mental maps in their heads, but this does not mean these maps are visual and the main components of these maps may be tactile and auditory.
4. Some blind people use movement to form their mental maps and may also imagine walking along the route in their route descriptions.
5. There are some correlations between the senses and types of sensory input used in route descriptions and mental maps.
6. The type of route may affect route descriptions. For instance, there may be more use of auditory or surface change landmarks as indicators of where to change direction on more irregular routes and more warnings or information about obstacles on more 'dangerous' routes.

	Information used in route	Information used in mental maps
P1	Mainly descriptions & features, less directions. Path unevenness, width, slopes, level changes – cane, walls + gratings, birds singing, road crossing, post on tactile paving.	Mentally draws map like schematic diagram. Tactile sensations when describing route. Movement along route – learn & remember it, form mental map. Visual, audio, tactile and smell.
P2	Mainly directions/instructions. Turnings, types of surface, side of path to walk for right position for next turn/curve - left for turn left. Notes obstacle locations to avoid.	No information provided directly or indirectly.
P3	Descriptions of road/crossings. Tactile pavement, trees. Sounds – traffic, children; cane - walls at side. Turn at landmarks e.g. closed sound. Small slopes up/down.	Sounds – major role. Mental image of way, sounds, wind. Map as if hearing in mind. Open/closed spaces. Combines audio and other info - shade/light info – sees brightness in mind. Not use smells or touch.
P4	Auditory info. Landmarks – air conditioner, changes in wind to find turning, small slopes, wall - shore line, change in surface material.	Sensory info – audio, tactile, visual, smell - to draw mental map in head. Main elements auditory and tactile. Remembers some sounds as images.
P5	Description of movement along the route – walking straight, crossing a road, turned right/left, go round square, posts in path. Changes in wind – indicate where turn.	Remembers route as if walking on it, sense of space and in. Spatial sensations & sound difference - open/closed area, walls, no buildings. Info from sound.
P6	Focus on landmarks – high walls/houses, slopes/ramps to entrances, traffic on main road to turn, slopes. Quality of pavement, tactile paving.	Movement and direction changes to recognise go round square. Experience of relief diagrams, mental representation of square not visual or tactile.
P7	Focus on landmarks - type of surface, buildings and empty spaces - turns. Deduction – entrances from concrete ramps. as landmarks for turning. Egocentric object location - to left/right of self.	Purely visual mental map. Draws on memories of sight. Mark area using landmarks – building, tree etc Repeated visits to create map. Use mental map to give impression of seeing area, particularly if know well.
P8	Focus on landmarks – wind, sun, car noise, surface material, vegetation, football field; centre of track or preferably wall for straight line. Directions – straight on, turn.	Mental maps – largely visual. Also touch, sound and smell, but not experience them when remembers. Map gives impression of seeing. Do route once to produce mental map.
P9	Directions – walk to end, block etc, road crossing. Surface textures & quality, road width, sounds, slopes, playing field. Obstacles – face height litter bins, dogs. Sounds –air conditioner, classroom. Smells – expand existing info.	Visual mental map based on memory. – draws route like schematic diagram. Audio, tactile, smell memory. Discusses visual and other memories separately, associations for smell and audio memories. Imagines walking on route, Sense direction – audio, touch, smell.

Table 9, information used in directions and mental maps

6.3 Using the results in the design of electronic travel aids

Understanding how blind and partially sighted people travel, the information they use and how they form mental maps can have an important role in improving the design of ETAs and ensuring that they take full account of the end-user perspective. Effective ETAs should provide information that is useful to end-users and do so in an appropriate format. They should preferably support the formation of mental maps.

Existing ETAs have generally been of the one size fits all type, not taken account of differences between different (groups of) end-users and not offered personalisation options to better fit the device to the user. In the past cost was a barrier to developing ETAs specific to particular groups of end-users. This has changed with the widespread availability of smartphones and other mobile devices and the great variety of apps that can be used on them. Smartphones (and tablets) generally have a camera, GPS, accelerometers, magnetometer and gyroscope sensors for localisation, wide bandwidth speaker, high quality directional microphone, 3G (now 4G), WiFi and Bluetooth and low power consumption, making them well suited to travel and data collection and processing applications (Hersh and Leporini, 2017). Accessibility for blind people is frequently ensured by screen readers such as Talkback or VoiceOver or Zoom magnification. Apps can be relatively easily customised for particular groups of end-users and the use of an existing device reduces costs and may also reduce the time required for learning.

There is a body of work on ETAs, though sometimes the developments seem to be technology rather than end-user driven. However, technology should be considered a tool to meet end-user needs. There is also little work relating travel understanding to the spatial perceptions and representations of blind people and little attention has been given to this in travel aid development. The few exceptions include (Guerreiro et al., 2017), who consider the ability of blind people to construct sequential environmental representations and (Hersh, 2020a) who discusses the role of understanding of mental maps in travel aid development. However, considerable further work is still required. Giudice et al. (2021) consider the types of information that blind people in particular require to support safe travel and have an interesting design approach involving the user actively engaging with the system to receive navigation instructions. This does not specifically use spatial understanding, but could contribute to developing it. Guerreiro et al., (2018) investigate user behaviour with a cane or guide dog during indoor navigation and consider scenarios and contexts where this could lead to errors, as well as the recovery mechanisms and use their results to make recommendations for the development of navigation devices. This is again related to rather than specifically involving spatial understanding.

A variety of audio-tactile devices have been developed to support route learning and mental mapping in advance of travel. Interactive maps on phones or tablets can potentially also be used while travelling, though in practice it is likely that users will have to stop to consult them, giving a need for devices that can be used while moving.

Appropriately designed ETAs can contribute to both developing a mental map framework and providing content for it. Many blind people develop very good memories of route information (Hersh, 2020b). However there may be value in ETAs with a memory function to enable users to compare their memories with the information from the aid and fill in the gaps. This memory function review could be used to support developing, expanding or reviewing mental maps. ETAs which provide road names and nearby well-known landmarks would be useful in supporting mental maps, as this type of background information is helpful in asking directions or checking you are on the correct route. For instance, blind travellers are more likely to obtain useful information if they ask about the location of a well-known landmark than a side street or small shop. Having this information in their mental map enables them to both know what to ask for and to find their way from the landmark to their destination.

A further suggestion is ETAs involving an artificial intelligence or machine learning function. This could use user behaviour and queries to modify the types of information provided to them. There may be value in designing future ETAs of this type to be used in conjunction with the long cane and supplementing rather than trying to replace its obstacle avoidance functions.

6.3.1 Suggestions for guidelines and future ETAs

The following lists present a number of suggestions for guidelines for the development of future ETAs, as well as suggestions for new ETAs or ETA features. They have been obtained from analysis of the results and the literature. It should be noted that many of the suggestions will require considerable research. In some cases, preliminary research will be required to investigate feasibility.

Guidelines for ETA developments

- Active involvement of blind and partially sighted people in all phases of the design and development of ETA, including using co-production and other participatory design approaches. As indicated by a number of authors, the navigation cues required by blind people are often very different from those used by sighted people e.g. (Williams et al., 2014). In general, active involvement of end-users in design and development is required to ensure that the outcomes meet their needs and take account of their preferences.
- Providing options to customise devices without making them complicated to use, as there are, for instance individual differences between blind people (Gullay et al., 2009). This customisation could usefully include: (i) the format of device output e.g. speech, non-speech sounds, virtual sounds and vibro-tactile or other tactile; (ii) the format of user input/instructions; (iii) the types and details of information provided; and (iv) the option to turn pre-journey planning on and off.
- Inclusion of a variety of sensory and other information in route descriptions and other information provided by ETAs. This could include odours and changes in them (Koutsoklenis and Papadopoulos, 2011) and the type of surface and changes in it.

Suggested ETA features and functions to support mental mapping

- Memory function to enable users to compare their memories with the information from the aid and fill in the gaps. This could support reviewing and expanding mental maps.
- Artificial intelligence or machine learning function. This could use user behaviour and queries to modify the types of information provided to them.
- Provision of road names and nearby well-known landmarks to support mental map formation by providing information not otherwise available to blind people. This type of background information is very useful in asking directions or checking you are on the correct route.
- Using user interaction (Giudice et al., 2021) to trigger responses from the device to support developing mental maps and spatial understanding.

Suggestions for features and functions to support object identification

- Travel aids for supporting learning to recognise objects drawing on the users' and other blind people's object learning strategies.
- Data bases of object learning and other useful travel strategies.
- The use of camera identification of objects to support users learning to recognise objects with the long cane and/or their hearing. We consider that object identification via the cane or hearing is advantageous to blind people, as it can potentially provide more detailed (relevant) information and does not risk distraction or blocking environmental information.

6.4 Limitations and further work

The main limitations of the research were the small sample size, though this is not uncommon in this type of work, and, in particular, the fact that only two participants used both routes. This made it difficult to compare the descriptions of the two routes and make inferences about the impact of their different characters. On the other hand the study obtained very rich data which benefited from analysis in depth and this would have been more difficult with a large number of participants.

A further limitation was the lack of participants who were blind since birth so the findings may not reflect people who are congenitally blind. Although the differences between participants' experiences were discussed they were not related to their personal characteristics.

A final limitation was the use of only one coder. This was mitigated by checking and confirmation by the second author. The authors decided this was an appropriate solution rather than delaying the analysis until the second author was available to do this, due to the nature of the material and the first author's previous experience.

An important methodological issue was obtaining information about participants' mental maps from analysis of comments made while walking and of additional commentary provided subsequently, with a particular focus on the senses used. It may be possible to use brain scanning while walking to obtain information about the sensory areas of the brain activated. This would provide some, though probably not full, information about the senses involved in developing mental maps, but not about their details. Therefore, proxy approaches are required, in this case using . Other approaches involve the use of (tactile) drawings, but there has not yet been a comparison of the different approaches.

Important areas for further research include the following:

- Further investigation with a larger sample, including congenitally blind people to confirm or modify the preliminary inferences in section 6.2 about the relationship between the information used in route descriptions and mental maps.
- Investigation of the relationships, if any, between mental maps and the sensory information used in them and factors such as gender, age, country/culture and native language.
- Further research and development with the active involvement of blind people to apply the suggestions for the design of ETAs in section 6.3 in practice and test the results.

7. **Conclusions**

In this paper we report an experimental study involving nine blind participants following two routes of very different characters and stating their observations while doing so. This was followed by the participants providing descriptions of each route and then answering questions about the route and how they used and retained the information, as well as some demographic information. Analysis of the results was used to answer three research questions about (i) the identification of environmental features while travelling and the senses used to do this; (ii) the use of sensory, route and other environmental information to form spatial representations; (iii) the implications for the design of travel aids. The responses to these questions are discussed in detail and form the main contribution of the work, and we note the limited existing work in all these areas.

Unlike much of the existing work, this study was carried out in Brazil rather than Europe or the USA and we suggest in the discussion of further work the need for investigation of the impact, if any, of demographic factors including country and native language on the spatial representations of blind people. A study involving two real routes with very different characteristics was used to investigate blind people's spatial behaviour and representations and the sensory information on which they are based in real travel situations (while recognising that measurement may cause some distortion), whereas much of the literature uses studies in artificial environments to compare the spatial performance and understanding of blind and sighted people.

Analysis of the results showed that the items mentioned by participants in their route descriptions could be organised into the four themes of directions/actions, warnings and alerts, surface or path features, and features of the route. The route features could be further divided into objects and locations, with 'object' understood in the widest sense to include, for instance open and closed spaces. Participants were found to draw on different combinations of information from all their senses in identifying objects and deriving mental maps. They were able to identify a wide range of objects, either directly from sensory information or by deduction and inference. The analysis also led to a number of inferences about the relationship between the information used in route descriptions and mental maps. Final this analysis in combination with the literature was used to produce a number of guidelines for the development of future ETAs, suggestions for new ETAs and ETA features and suggestions for further research directions.

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Appendix

	P1h		P3		P5		P6		P9	
Feature	M	DD	M	DD	M	DD	M	DD	M	DD
Above	3				1					
Behind							1			
Bird	15				1		2		1	
Broader	5									
Buildings including shops	5						2			
Bus, motor bike or lorry	3						3			1
Car	22	0	3	1	1	0	10	0	1	5
Closed	9	1	1	2	3	0	4	0	0	1
Corner	4		1		3					2
Distance to							3			
Dog	6				1		2		1	1
Door/gate	7		1		1					2
Entrance	1		2				7			2
Grate/grating	9		2	2	7		1			
In front							1			
Inside	1						1			
Machinery	2		2				1			
Narrow(er) pavement	9									1
Navigation and actions	2		1		1		1			3
Noisy or quiet	1						6			2
Odour	4						4			2
On the left	2	1	10	4	8	0	5	0	0	3
On the right	1	0	3	2	7	0	7	0	0	1
Open	13	1	13	3	8	0	5	0	0	0
Opening	7									
Other constructions	3				3				1	1
Other objects	8	0	3	0	1	0	3	0	1	6
Pavement quality/surface	13	0	4	1	3	0	3	0	4	5
Person	8		3		1		5			1
Post	9	1	4	1	5		2		1	
Puddle, hole or drain	4				3		1			
Ramp or inclination	9	0	3	0	0	0	4	0	4	0
Road	5		1		1		3			4
Sign			1	1	4		1			
Slope down	10		10		7	1	1			
Slope up	8		14	1	6					
Sounds	5		3		3		5			1
Step	5	0	0	0	2	1	1	0	2	0
Sun			1		1		4			
Tactile/alerting paving	39	0	4	0	15	0	0	0	2	4
Turn or turn back	2		1		3		3			2
Unidentified object	5		1		2					1
Wall	21	0	3	3	17	0	5	0	0	5
Wind	2		3	1	1		3			2
Number of features	280	3	80	17	102	2	110	0	20	52

Table A1 Summary of different features commented on by participants on external route

Internal Route

	P1h		P2		P3		P5		P6		P9	
References	M	DD	M	DD	M	DD	M	DD	M	DD	M	DD
Open					2		2					
Open on the right												
Open on the left		1			2	1						
Opening or more open	9				5	2	4		1			
More open to the right					2		1		1			
More open to the left					2		1		1			
Open above	3											
Open space	1								1			
More open space to left									1			
Open on right, closed on left						1						

Table A2 Example of the details of the information commented on by participants

	P2		P3		P4		P7		P8		P9	
Feature	M	DD	M	DD	M	DD	M	DD	M	DD	M	DD
Air conditioner	7	1	2	1	3				1	4		
Banana trees	1						3	2			1	
Birds	1		1					1	1	2	2	
Bright/dark			3		1						1	
Building	2	1						4		2		
Car	1	1							1	1	1	1
Door		1			1				3			
Down slope	2		3	2	3				1		1	
Drain					1					1	4	
Entrance	1		1	2	2			1		1		
Feature behind	3	1						3				
Feature in front	11	4		2								
Feature on the left	16	4	4	2	1	1	3	6	3	5	6	
Feature on the right	4	2	4	1	3	2	6	7		3	6	
Grate/grating			1	1	1		2			2		
Guide on ground/tactile								1	3	1		
How walks/tracks	1		2		3			1	6	1	1	
Leaves	10	2	2		8		2		2	2		
Level/uneven surface	3	2		1	1					1	1	
Mid-line	1				3					2		
Miscellaneous objects	10		1	1	2		1	1	1	1	4	
Music	2	2	1	2								
Odour	3					1				5	3	
Open/closed	3		4	2	3	1				2		
Path - location or features	1	1			3		1	2	4	1	2	
People other	2	1			1	1	1	6	2	6	2	
People talking					1	1	1	2	2	5	2	
Quiet/peaceful				1				1	1	2	1	
Ramp or slope up	3	2	3		2		1	2	1		1	
Shady/cool			1	2						3		
Sounds	8	4	1	1	1			5	2	6	3	
Stones/pebbles (ground)			1		3						2	
Surface type	5	3	1			1	2	5		6	3	
Surface type: change	2	2	1	1	2		1	1	1		1	
Trees	7	2	4	5	6	1		2	2	8	3	
Turn/continue to right/left		1		2	4			3		2	1	
Type of space	1		1		1		4	2				
Unidentified objects	1	1						1	1		1	
Vegetation	2	1			1			1	2	3		
Wall	4	2			2	1	1			2	3	
Water						1				4	2	
Wide(r)/narrow	3								3	2	2	
Wind	4	3	1		2			1	3	5	2	
Window	1				4	1						
Number different features	78	27	30	23	62	6	21	39	31	64	43	1

Table A3 Summary of different features commented on by participants on internal route