DESIGNING ASSISTIVE TECHNOLOGY TO SUPPORT INDEPENDENT TRAVEL FOR BLIND AND VISUALLY IMPAIRED PEOPLE

PART I : MODELLING THE TRAVEL PROCESS

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0.1 Learning Objectives

- Understanding why it might be useful to model the travel process.
- Learning about some of the existing empirical research on mobility, wayfinding and spatial understanding.
- Learning about the existing models of the travel process and developing an understanding of their advantages and limitations.
- Understanding some of the factors that should be considered in models of the travel process.
- Learning about a new three-part approach to modelling the travel process.

0.2 Organisation of the Tutorial

Section 1 is divided into two parts. The first part discusses the differences between the types of information through the different senses, whereas the second part considers the reasons for and benefits of modelling the travel process. Section 2 provides a brief overview of some of the relevant literature, introduced by a categorisation of different types of empirical research studies in the area. Section 3 discusses the empirical research carried out by the author and concludes with a list of factors, drawn from this research and a study of the literature, to be considered in any map of the modelling process. Section 4 presents a new modelling approach based on three main components and concludes with a discussion of the need to validate the model and ways in which this can be done. Conclusions are presented in Section 5.

1. Introduction

1.1 The Use of Sensory Information to Support Independent Travel

The ability to travel (independently) is very important for participation in all aspects of modern life, including work and leisure activities. There are many blind and visually impaired people who are very successful at independent travel, whereas others rarely if at all go out on their own.
All the senses have advantages and disadvantages and applications for which they are particularly suited. Vision, touch, hearing and smell can all be used to perceive external

cues, which can be used as landmarks. However, landmark information obtained from vision and touch is more likely to be fixed and not vary with the time of day or season, whereas the availability of auditory and gustatory landmarks will vary with the time of day and other factors. Both vision and touch can be sharply focused.

Vision is distinguished by having a large spatial field and the ability to provide overview information from a large area at one time, whereas touch has a very limited field, requiring information to be perceived sequentially and retained in memory (Ungar, 2004). Vision is able to provide direct and reliable information about the relationships between external objects and gives coincident body-centred and external reference frameworks, (Millar, 1994). It can provide information from both directions along a route and integrate the locations of spatially separated landmarks and prior knowledge of the relationships between objects. Hearing has a large spatial field, but, unlike vision, is unable to process a large number of signals at the same time, with the different signals competing and interfering with each other rather than being combined to produce useful information. In addition hearing is less precise than vision in locating and identifying objects (Ungar, 2004). Touch has a small visual field. It can be used to locate objects within this field very precisely, but not objects at any distance. In addition, it is generally less easy to identify object with touch than with vision. The sense of smell has a large field, but is very imprecise at locating and identifying objects (Ungar, 2004). Thus, visually impaired people generally do not have a preview of objects or obstacles.

Touch and movement can be combined to provide information about shape, configurations and the relationship between surfaces, but it has been found that memory for shapes and configurations obtained from vision is better than that obtained from touch (Millar, 1995). It is generally much easier to remember information if it is well organised and coded, regardless of how it has been obtained. According to the CAPIN (convergent activity processing in interrelated networks) model information from the different senses is both specialised and complementary and overlapping (Millar, 1994, 1995). Both specialisation and overlap or redundancy are important for understanding and coding spatial information (Millar, 1995) and prior knowledge and experience are generally used to help make sense of the perceived information. In addition understanding of space generally requires the reconstruction of fragmentary information, whether haptics or vision is used, but the delays involved in information processing are greater for haptics than vision.

Although there is often a tendency to consider the representation of space as a purely visual activity, there is evidence that this is not the case and that vision is neither necessary nor sufficient on its own for spatial coding (Millar, 1988). Spatially relevant information can be obtained from hearing, touch and movement, as well as vision, and form the basis of spatial coding. In particular, blind people are able to code spatial information, though both blind and sighted people often make mistakes in tasks involving the processing of spatial information. However, a significant link has been found between visual experience and the type of spatial representation used (Byrne and Salter, 1983; Millar, 1975a, 1976, 1979) and experience has been shown to be important for the development of accurate cognitive maps (James, 2006). In considering the representation of environmental information, it is useful to consider both the sensory modality by which this information has been obtained and how the information is coded.

Studies have found that blind children tend to use body-centred reference frames and memory rather than external cues for movement information in spatial tasks, but these approaches could be used in conjunction with other cues on distance and direction to provide redundant reference information (Millar, 1995). However, the issue may be experience of environmental exploration, rather than specifically visual experience, with early and congenitally blind people tending to have been more sheltered and therefore to have had less of this experience. Thus, congenitally and early blind people may require specific training to make up for their limited knowledge and (visual) experience of spatial layouts. There is also a need for further research on the role of early experience of exploring space in enabling blind people to develop spatial representations and travel skills, as well as the extent to which such early experience negates the perceived advantage of sight compared to haptics and audition in developing accurate mental representations of space.

Late or adventitiously blind people have the advantage of previous visual experience which gives them knowledge of specific environmental features and makes it easier for them to have a holistic perspective of spatial arrangements, such as complex traffic layouts. They also have the visual feedback information generated by movement and retain this sensitivity after becoming blind (Thinus-Blanc et al, 1997). However, congenitally or early blind people have the advantage of having considerable experience of using their other senses. They are therefore accustomed and consequently probably better able to obtain, process and interpret spatial information from auditory, haptic and other non-visual channels.

There have been three main theories of the understanding of spatial concepts by congenitally blind people: the deficiency, inefficiency and difference theories (Ungar, 2004). The deficiency theory, which came out of studies carried out from the 1920s onwards mainly on tabletop tasks, (von Senden, 1932) has been discredited and is largely of historical interest (Jacobson, 1998). It states that the lack of visual experience of congenitally blind individuals prevents them from developing a general spatial understanding. According to the inefficiency theory visually impaired people are able to understand and mentally manipulate spatial concepts, but do so less efficiently, due to the reduced efficiency of auditory and haptic compared to visual information (Reiser et al, 1986). According to the difference theory, visually impaired people have the same abilities to process and understand spatial concepts, but do this differently and often more slowly than sighted people (Juurmaa, 1973). However, it has also been shown that many of the differences are due to factors such as reduced access to information (Passini and Proulx, 1988), rather than differences in cognitive processes. All these theories are limited by relating the spatial understanding of blind people to that of sighted people, as the 'norm' and may provide more information on attitudes to blind people than about their spatial representations.

1.2 Modelling the Travel Process

Models provide a representation of a particular real object or system, in this case the travel process. They are generally more accessible and easier to manipulate than the underlying real system: they are generally of smaller scale with regards to both their time and space dimensions, involve a description, drawing, mathematical equations or three dimensional construction rather than real people and complex objects and involve assumptions and simplifications. Models can be used to support research and develop understanding. Analysis, simulation or other investigation of the model can be used to investigate the behaviour of the underlying real system. However, it is important to understand the differences between the model and the real system and that empirical verification may be required to test the conclusions obtained from analysis of the model.

More specifically, the aim of developing a model of the travel process is to provide a framework, which has a number of applications, including the following:

- Testing and modifying hypotheses about the travel process and spatial understanding.
- Supporting further work on investigating the factors that support independent travel by blind and visually impaired people and what measures are required at an individual and societal level to improve their mobility.

- Supporting the classification of the different approaches to travel and different types of travel processes used by different groups of people and the factors which determine which type of travel process a particular individual or group of people prefers.
- Investigating the match between current assistive technology provision and the travel process and determining where there are gaps and which stages of the travel process require additional assistive technology or more accessible environments.

The consideration of existing models and presentation of a new one will draw on the following principles:
- A holistic approach to the different tasks involved in developing mental representations of space and travelling successfully which can be applied independently of visual status, while noting any significant differences for different groups.
- Differences in approaches to modelling space and travel are based on a number of factors, including differences in cognitive style and other personal factors rather than just visual status, though further research will be required to investigate the impact of the different factors.
- Many of the problems encountered in travelling by blind, visually impaired (and other disabled) people are due to lack of information which is accessible to them, inaccessible transport systems and infrastructure and lack of early experience of exploration of space and independent travel, often due to being overprotected. Though some further research will be required, there is already a body of knowledge on making information and environments accessible to blind, visually impaired (and other disabled) people, as well as the value of early experience.

2. Overview of the Literature

2.1 Empirical Research

A number of empirical research studies of travel behaviour or its components and spatial representations of blind, visually impaired and sighted people have been carried out. These can be categorised as follows:
- Wayfinding or the ability of groups of people with varying levels of sight to follow particular routes and carry out a number of wayfinding tasks.
- The ability of blind and sighted subjects to estimate distance and direction between locations under a variety of different conditions and to point to various locations from other locations.
- The mobility and wayfinding performance of blind and visually impaired people on real or artificially designed routes and with and without different assistive devices.
- The mobility and wayfinding performance of blind, visually impaired and sighted children.
- Object location by blind people and the strategies used.
- The most effective methods for enabling blind people to learn new routes, including the use of tactile maps.
- End-users' opinions of different orientation and mobility devices, as well as their preferences for receiving information in different formats.

A brief overview of the studies in most of these categories will be presented in this section in addition to an overview of the literature on cognitive maps and spatial representations

2.2 Cognitive Maps

The terms mental and cognitive map have often been interpreted in terms of map-like representations of the real world. However, it is more useful to understand the term in its mathematical sense of representation or correspondence i.e. how people represent the real world to themselves, in this case so they can move around in it. There are a number of different definitions (Kitchin, 1994). The term 'cognitive map' was first used by Tolman (1948) and has since generally referred to very high level spatial processing, involving a survey type representation of the environment, which allows efficient movement between places (Péruch et al, 2000). The traditional definition is 'a process composed of a series of psychological transformations by which an individual acquires, stores, recalls and decodes information about the relative locations and attributes of the phenomena in his (sic) everyday spatial environment' (Downs and Stea, 1973a, p. 7). Thus mental maps involve both internal or cognitive representations of the structures, features and relations of space and knowledge, impressions, information, images and beliefs about the environment (Hart and Moore, 1973, p. 248; Moore and Golledge, 1976, p. xii.).

Thus a cognitive map is a mental construct which is used to learn, understand, simplify and code, interpret and explain the environment and human interactions with it (Kaplan, 1973, Walmsley et al, 1990), as well as supporting spatial thinking and communicating knowledge about space to other people (Downs and Shea, 1977). Cognitive maps generally include information about object locations and spatial relations (Kaplan, 1976) and involve a series of knowledge structures with different levels of detail and integration (Golledge and Timmermans, 1990). They can provide the information required for spatial decision making (Briggs, 1973), to aid locomotion and movement in the larger physical environment and to stop people from getting lost (Siegel and White, 1975). Cognitive maps are also used to support wayfinding and organise (spatial) experience (Lynch, 1960). Cognitive mapping is an interactive process (Downs and Stea, 1977) and motor activity, such as movement in space, is considered to be necessary to link the external environment to the mental representation (Held and Rekosh, 1963).

Mental maps generally have a degree of simplification and schematisation and are not always 'map-like' in an obvious sense. Individuals tend to include the features they consider relevant, and not remember those they consider irrelevant, and to structure their cognitive maps in ways which are personally meaningful and facilitate use. They may also add elements which are not actually there, but which are assumed to be present based on past experiences and expectations of what should be found in a particular type of location (Downs and Stea, 1977; Bruner, 1959). In addition, limitations of perception and memory will affect the form of cognitive maps.

Currently there are many questions about mental maps, including what properties and components of the environment are represented and how are they represented, what internal structures support the representation and the format in which the information is presented (Palmer, 1978). However, to date only partial answers have been obtained and further work will be required to develop a fuller understanding of mental maps of space and the travel process. The even more fundamental question of whether mental maps of space are purely a theoretical construct or represent the real cognitive processes of blind and sighted travellers has received very little attention in the literature. This paper aims at filling some of the gaps and contributing to the development of this understanding.

2.3 Studies of Cognitive Maps and Spatial Knowledge

A range of different methodologies for assessing the mental maps of blind and visually impaired people have been developed. However, many of the results are based on very small samples, use laboratory rather than real world situations and provide different types of spatial information, which affects performance and makes comparison difficult. Therefore the validity and utility of the results could be improved by using several mutually supportive tests to try and obtain a complete picture of the respondents' knowledge, testing the reliability of techniques rigorously before a study is carried out and using at least 10 subjects and complex real world environments (Kitchin et al, 1997).

Research has shown that congenitally blind people are able to learn relatively complex routes, make journeys and have an overall understanding of spatial layouts which enables them to carry out complex spatial operations, such as finding shortcuts. However, they make more detailed preparations and more frequent wayfinding decisions and use more information and landmarks than sighted people in order to do this (Passini and Proulx, 1988). Therefore, despite the differences in their previous visual experience and memories, congenitally blind and sighted people are able to carry out the same cognitive spatial operations and have operationally equivalent spatial representations, though there may be differences in the details.

A study of a number of wayfinding tasks by people with different levels of sight found the sighted group to perform best on average, followed by the visually impaired group, the congenitally totally blind group and then the adventitiously blind group, who performed similarly to the blindfolded sighted group. The congenitally blind group completed nearly half of the tasks and statistically held the middle ground, being closer in performance to the sighted and visually impaired groups on some tasks and the adventitiously totally blind and blindfolded groups on others (Passini et al, 1990). Contrary to the interpretation by Passini et al that previous visual experience decreases performance, it seems most likely that performance of visually impaired people is dependent on or at least influenced by the extent of their experience, adaptation and skills in using senses other than sight. In addition this study implies that vision and visual schemata are not required for spatio-cognitive competence (Passini et al, 1990).

More attention has been given to the aggregate or on average differences between groups of blind and sighted people in their performance of spatial tasks than the differences between individual blind people. However, there are significant differences between individuals, making it important to understand the strategies used by the best performers so they can be taught to other people. It is also possible that the significant factor in these differences in performance is not the strategies themselves, but the efficiency with which they are used. However, there may also be differences which are either based on knowledge which is difficult to codify or which are innate. Thinus-Blanc and Gaunet (1997) concluded from a study of the literature that the age of onset of blindness has a limited effect on the completion of spatial memory tests and that the spatial skills of early blind people are dependent on the interaction of a range of different factors. They also very usefully suggest that further research is required to investigate what types of strategies for obtaining information lead to improved spatial skills, as well as how such strategies can be taught. It would also be useful to investigate the role of early experience of spatial exploration in developing spatial skills.

2.4 Studies of the Ability to Estimate Direction and Distance

There has been a body of theoretical and empirical research on the estimation and representation of distance and angle by both blind and sighted people. The research on cognitive distance has generally assumed that it is a linear (Caldwallader, 1973) or power (Bratfisch, 1969) function of real distance. Further common assumptions base cognitive maps on Euclidean geometry, as a (non-relativistic) representation of the real world. However, it has been found that while aggregate distance estimates are transitive or commutative i.e. the distance between two places is not dependent on the order in which they are considered or pairwise comparisons made (Cadwallader, 1979), the distance estimates of individuals are not. There is also a tendency for the distances between pairs of nearby city to be overestimated relative to the distances between pairs of more distant cities

(Holyoak and Mah, 1982) and curves in roads and rivers to be straightened out (Chase, 1983; Milgram and Jodelet, 1976). Therefore, perceptions and estimates are influenced by subjective factors. Further investigation will be required to determine whether this does mean that individuals reject Euclidean geometry or use a type of Euclidean geometry which is modified by subjective factors.

It has found that congenitally blind people make similar errors to sighted people in estimating distances in their urban neighbourhoods and in pointing north, but have significantly greater errors in pointing to local buildings from an imagined direction (Byrne and Salter, 1983). Distance estimates in a familiar location have been found to be based on an underlying ratio scale of distance when made by either blind or sighted subjects in a familiar location, as have those of sighted subjects in an unfamiliar location (Haber et al, 1993). Haber et al suggest that this indicates that these blind and sighted people are able to use a consistent scale to judge distances.

Errors in estimating direction along a short urban route have been found to increase with distance and to be much greater on average for congenitally than late blind children, though some congenitally blind participants were found to perform at the same level as sighted ones (Dodds et al, 1982). Visually impaired children's distance judgements have been found to be more closely correlated with functional (distance travelled between points) than Euclidean (straight line) distances (Ungar et al,1996). Since research also indicates that estimates of straight line distances are more accurate when obtained from maps and of functional distances from walking routes, this is probably due to the children's distance information being obtained from walking the route rather than studying a map. A study of the imagery used in the estimations of distance between locations by sighted students found that older students who knew the locations better used more abstract maplike and three dimensional imagery and obtained more accurate distance estimates (Foley and Cohen, 1984). However, it is not clear whether the improved estimates resulted from greater knowledge of the building or the use of better imagery.

Studies show that both congenitally and adventitiously totally blind and sighted people are generally well able to judge perspective and do not have a speed/accuracy tradeoff in judgements of direction while walking. Previous visual experience has been found to facilitate the development of sensitivity to changes in perspective when walking without vision. However, sighted subjects have been shown to perform equally well when exploring space visually and nonvisually. Therefore, it is probable that sensitivity to changes in perspective is independent of whether spatial and object information is obtained visually and the differences found may be the result of greater experience of exploring space rather than visual experience. Movement has been found to aid perspective judgements on short walks across large rooms, but may not do so on long, slow or circuitous walks or when travelling in a vehicle (Rieser et al, 1986).

2.5 Perception, Navigation and Orientation, Learning and Identifying Objects

A number of studies have examined the performance of blind and visually impaired people in locating objects and the strategies they use to do this. However, the results of the different studies are not consistent, probably due to the use of different methodologies, differences in the participants' experiences and other factors. It is also not always easily apparent how best to interpret the results of studies.

Thus, one study found that congenitally blind participants performed less accurately and took longer to locate landmarks they had been shown in an unfamiliar environment (Rieser et al, 1982), whereas another study found similar accuracies, but higher response latencies (Loomis et al, 1993), implying there may be a speed/accuracy trade-off (Ungar, 2004).

However, the apparent discrepancy may be due to the greater experience of independent mobility of the latter group of participants, supporting theories that practice increases spatial ability. In the previous section it was noted that there is not a speed/accuracy trade-off in judging perspective when walking. It is possible that some types of perceptions or evaluations of the environment are affected by a speed/accuracy trade-off, but that others are not. There is also conflicting evidence as to whether the performance of congenitally or early blind people on spatial tasks is poorer or equal to that or late blind or blindfolded sighted people (Thinus-Blanc et al, 1997).

Studies of the tactile maps of a large campus produced by blind and sighted students found that blind students were able to identify fewer building elements and had a tendency to organise them into a number of small independent units without considering the connections between these different units. They also tended to represent curved paths as straight (Casey, 1978), though this may be an artefact of ease of representation or lack of interest in path curvature rather than lack of knowledge as such. However, very accurate representations were produced by some of the blind students with good independent mobility (Casey, 1978).

A number of strategies used by blind people to learn the layouts, generally of objects in a large room, have been identified. These include perimeter (walking round the perimeter of an area in a constant direction to identify its key features), grid (taking straight line paths from one side to the other to investigate internal elements), cyclic (visiting each object in turn and returning to the first object) and back and forth (moving repeatedly between two objects) strategies (Hill and Riesere., 1993; Gaunet and Thinus-Blanc, 1996). In general the use of more diverse strategies and strategies that link objects in a systematic way has been found to be more successful than the repeated use of one strategy which does not link objects, both in terms of finding objects and speed of performance (Hill and Rieser, 1993). Some studies have found that early blind participants use less efficient strategies, perform less well and have less spatial knowledge than late blind and blindfolded sighted participants (Gaunet and Thinus-Blanc, 1996).

A degree of care is required in interpreting the results of studies, in particular, to ensure that researchers do not interpret them in the light of their own values of or impose their own views on participants. For instance, one study (Dodds et al, 1982) found an apparent lack of spatial awareness and an inability to track their positions relative to two spatial locations in a group of 11 year old congenitally blind children, despite the fact that they were all independently mobile and able to complete a route successfully. However, this is consistent with the view that the important issue for blind children and adults is independent mobility, with spatial awareness being considered desirable, but not essential. Although their models of the school campus were frequently less accurate than those of sighted children, some of the blind children produced very accurate models, with accuracy increasing with independent mobility (Dodds et al, 1982).

2.6 Tactile Maps and Route Learning

There have been a number of experiments to try and determine the most effective methods for enabling blind people to learn new routes. Many of the results have found benefits in the use of tactile maps. For instance, Espinosa et al (1998) found that early blind subjects obtained better practical and representational knowledge of a 2km complex route from a tactile map which they studied in advance and could consult on the way then from being guided by an instructor who gave verbal descriptions of the route between landmarks. When participants consulted the map in advance but not en route they performed at the same level as when directly experiencing the environment (Espinosa et al, 1998). Blind people have been found to learn a moderate length route typical of a small town much faster with a tactile map than with a description on a tape recorder or by being guided along the route (Brambring and Weber, 1981). In addition the use of a tactile map seemed to facilitate retention of the information, since the performance of subjects who used the tactile map was also better than that of the subjects who did not when retested after 12 weeks.

There has been some investigation of the strategies used by blind and sighted people in learning maps. It has been found that visually impaired people are more likely to read individual feature names, describe features without interpreting them and search for features they have found previously, whereas sighted people use a wider range of strategies, many of which involve structuring and linking the information. Thus, visually impaired map learners have been found to have a tendency to focus on local and separated features of the map, whereas sighted learners concentrate on patterns. This structuring of information is presumed to be responsible for the better performance of sighted map learners. The visually impaired learners who performed better tended to make more references to the map framework, whereas the poorer learners made more unstructured attempts at memorisation (Blades et al, 1999). However, contrary to expectations, the use of a template did not seem to facilitate map learning, though this may have been due to the choice of inappropriate type of templates problems in correlating map and template information.

Studies indicate that tactile maps can be used by even young blind children to obtain knowledge about environmental spatial structures and make spatial decisions. They may provide a means of understanding external frameworks that is not possible through direct experience alone. For instance, studies of environmental learning have found that 5-11 year old totally blind children learn the environment more accurately from using a tactile map than direct exploration (Ungar, 2004). The addition of audio information to a tactile map can further enhance route learning. For instance, it has been found that students produced consistently better and slightly more accurate maps of the route, as well as being slightly better able to estimate distances when learning the route with an audio-tactile map than with an instructor (Jacobson, 1998).

3. Empirical Research by the Author

3.1 Methodology

Data on the mobility and spatial knowledge of blind, visually impaired and deafblind people was obtained by the author through a series of semi-structured interviews. A semi-structured approach was chosen, since this both provides enough structure to ensure that all the topics of interest are covered and has sufficient flexibility to enable issues raised by the interviewee to be explored and the balance of time spent on different topics to be varied. In addition, the semi-structured approach increases the likelihood of the interviewee discussing their own experiences, opinions and preferences rather than reflecting back those of the researcher.

Interviewees were initially asked to introduce themselves and to talk about their lives, activities, interests, visual impairment and the role of travel in their lives. Topics arising from this introduction were then explored in more detail. Other topics covered included:

- The use of travel aids
- Orientation and mobility training
- Public transport
- Buildings and urban environments
- Description of a route and a familiar room or other space
- Spatial representations
- Learning new routes

- Landmarks used and any changes in them due to changes in vision/visual impairment.
- Education and employment
- Any changes over time in their experiences of getting around.
- Attitudes and support from family, friends and the local community.

Contacts for interviews were obtained through organisations of blind, visually impaired and deafblind people, as well as via researchers working with them. All interviews took place in the language of the interviewee. Interpreters were not used other than for a small number of interviews with deafblind people using contact or visual sign language. Interviews took place in the office of an organisation, another convenient location for the interviewee or by telephone and had very varying lengths of between 30 minutes and three and a half hours, depending on a number of factors, including the issues that arose and the amount of time the interviewee had available. To date 38 interviews have taken place in France, 63 in Poland, 20 in Spain and 18 in the UK. Further interviews are planned in the UK, Spain and Tunisia, as well as possibly Russia and Italy. The people interviewed had a wide range of variation with regard to age, education, occupation, type of visual impairment and age of onset and degree of independent mobility. The sample had a reasonable gender balance, with slightly more men then women and included people from ethnic minorities, as well as people with both hearing and visual impairments and one deafblind wheelchair user.

3.2 Preliminary Observations

The formal analysis of the interviews has not yet taken place and it is therefore only possible to make a number of observations, some of which may be modified after the formal analysis has taken place. The first and probably the most important observation is the difference between familiar and unfamiliar routes and places. Many blind and visually impaired people only travel in familiar places and others only go to unfamiliar places with reluctance and find the experience difficult and stressful. The difference between familiar and unfamiliar places seems to be a consequence of increased knowledge which allows the anticipation and expectation of obstacles and facilitates their avoidance. It also to a large extent automises the process of knowing your location on the route and allows it to take place unconsciously. Although this reduces the demands for attention and concentration, independent travel by blind or visually impaired people is tiring and generally requires a considerable degree of concentration and attention even in familiar areas. Therefore, an important feature of an model of the travel process should be the inclusion of the difference between known and unknown places and the transition between the two i.e. how places and routes are learnt.

Other observations include the fact that blind and visually impaired people require access to the following types of information listed below, though there is not a complete separation between the types of information. For instance, shorelines and obstacles can also be landmarks. In addition, the different types of information are often obtained simultaneously and, though there are genuine differences in the way the different types of information are used, the categorisation is not one blind or visually impaired travellers would necessarily use in practice.

- Shorelines, such as walls, grass verges and the pavement, which they can remain parallel to in order to walk in a straight line.
- Landmarks of various types (visual, auditory, gustatory and tactile), though with familiarity recognition of location becomes unconscious.
- Obstacles, including unexpected occurrences, such as the presence of road works.

It should be noted that shorelines are used largely by blind and visually impaired people rather than sighted people and that there are significant differences in the use of information by blind people with a long cane and a guide dog. Guide dog users have less direct access to information and depend on the dog for walking in a straight line, but need to be aware of the route they are following to ensure the dog does not go off somewhere else. They are able to travel across open spaces, which is generally not possible for blind people using a long cane, due to the lack of information and landmarks. This leads to the further observation about the importance of access to information and the impossibility of locomotion in an area in which information is not available.

Other observations include the fact that the majority of people with some remaining vision seem to use only visual landmarks, regardless of how little they can actually see. However, it should be noted that even very minimal vision can have extensive uses. Since a number of visual impairments lead to progressive vision loss and blindness, this raises the question of how people with these impairments progress to the use of non-visual landmarks and successful travel as a blind person rather than a person who relies on their vison. This may require additional orientation and mobility training. In addition, a number of visually impaired people have significantly less vision at night or in bright sunlight, implying that they could possibly benefit from using different approaches to mobility and sources of information in different conditions: a visual approach with largely visual sources of information in good visual conditions, generally adequate, but not over bright lighting, and a more mixed approach using a combination of visual and non-visual sources of information in poor visual conditions. Blind people and visually impaired people who use non-visual as well as visual landmarks, generally use a range of sources of information, trying to take advantage of all the available information and generally do not prioritise one type of information over another or have a main source of information, but rather synthesise all the available information. They are also frequently able to make use of information, particularly from sounds and odours, which is only available at certain times of the day (or night) or at certain times of the year.

However, access to auditory information is particularly important. Consequently, many blind and visually impaired people prefer not to use mobility aids which provide auditory information through concerns that this will block their access to environmental information. Other people, such as users of the Télétact electronic cane, are happy to do this, as long as the information is provided through only one earphone and consider that the use of the aid enhances their mobility without blocking access to environmental information.

A number of blind and visually impaired people are unwilling to use a cane or even ashamed to be seen with one, giving rise to a need to change attitudes in society as a whole and to develop mobility aids which are other inconspicuous or look like devices, such as a mobile phone or PDA, in general use. While there is a degree of scepticism about technological aids for detecting obstacles, there is considerable interest in GPS based systems, with some people preferring a separate device and others GPS software on a mobile phone. There is also considerable interest in embedded environmental information systems, including on street names, bus, tram, train and metro numbers and destinations and real time information about the expected waiting times for buses, trams and rail and underground trains. There are also different opinions as to whether the loudspeaker which outputs this information should be situated on the user control device or in the environment, for instance at a bus stop or on a road sign. There is also disagreement as to whether audible traffic signals should be constantly activated or activated by a user control device. In all the countries surveyed to date the cost of assistive (travel) technology and the insufficiency of or difficulties in accessing sources of funding act as a significant barrier to blind and visually impaired people obtaining all the assistive technology they could benefit from.

Standardisation is very important for blind and visually impaired people and to a lesser extent for sighted people, as it facilitates locating information and objects of interest. This includes standard locations for road signs, standard layouts for a range of public facilities, including toilets in trains, and trains and buses always stopping in the same position relative to the platform or bus stop. In the case of visually impaired people, in addition to standard locations for information, attention should be given to the need for a high contrast between the lettering and the background, the size of the lettering and standardising locations at about eye height or lower, as it is very difficult to look up at a sign when approaching very close to it. There is less agreement about the preferred colour contrast, with many visually impaired people preferring white letters on black, but others preferring the opposite or other contrasts.

There are also both similarities and differences in the way different individuals travel, with success in independent travel seeming to be dependent on a number of factors, including confidence and the opportunity for independent exploration and travel from an early age and/or the onset of serious visual impairment. Overprotection and the lack of opportunities for independent mobility will generally lead to dependence, lack of confidence and lack of success in independent travel unless the overprotection is resisted. On the one hand, it is possible to successfully use very little vision to support independent travel. On the other, the degree of visual impairment with regards to both acuity and visual field is not necessarily the determining factor in independent mobility and there are totally blind people who have better mobility than some visually impaired people, particularly at night. A significant number of blind and visually impaired people feel unable to travel independently, either at all or outside a very limited number of known routes and consider that the most appropriate solutions for them would be services of accompanying persons and/or door to door transportation, provided either free or at very low cost to the user.

Many blind people prefer to learn new routes by travelling them for the first time in company with a sighted person, who explains the route. However, others prefer to be accompanied by a blind person, since it is only a blind person will know appropriate landmarks and other information to draw attention to. Some blind people prefer to prepare a new route by studying a tactile map, though there is limited availability of tactile maps, or having someone draw the route on their palm or with one of their fingers. A number of blind people consider a GPS to be the solution to overcoming the difficulties of travelling in unfamiliar areas, though the cost of GPS systems as well as other factors mean that most of these people do not use one.

It is probably experience in exploring new areas rather than previous visual experience as such, though the two are related, which is one of the important factors in determining facility in deriving spatial representations, as well as travelling independently. However, previous visual experience presents an advantage in allowing the derivation of graphical representations of space and enabling blind people to visualise objects using sensory information obtained from their other senses, possibly in combination with limited visual input. While some blind people with previous visual experience have visual representations of space, others and some of those without previous visual experience have spatial representations which use the senses used to perceive the information originally or remember routes by feeling themselves moving along them and perceiving various objects and other stimuli.

3.3 Factors to be Taken Account of in the Model of the Travel Process

In summary, combining the information from my empirical research with the information from the literature implies that the travel model should consider the following factors:

- The difference between familiar and unfamiliar routes and places and the process by which unfamiliar places and routes become familiar This leads to the idea of mental or cognitive map of space, while recognising that this is at least to some extent a theoretical construct rather than fully representing the real cognitive processes that take place.

- The importance of access to information and the impossibility of travelling in areas in which no useable information is available.
- The inclusion of different types of information, including on shorelines, obstacles and landmarks, as well as recognition that there is not a clearly defined separation between these different types of information.
- The synthesis of information from several different senses and assistive devices, as well as the use of purely visual information
- The use of assistive devices.
- Individual differences in travel style and cognitive processes.
- The importance of accessible information and standardisation of layouts and location and the barriers presented by the lack of accessible information and non-standardised layouts and locations.
- Different types of representations of space.
- Flexibility and the ability to take account of different approaches to travel, modelling space and user characteristics within one overall framework.

4. Models of the Travel Process

This section discusses the different models of relevance to the travel process. However, none of them represents the whole process. The following are the main types of models found in the literature and to be considered in this section:

- Models of cognitive maps.
- Types of space and environmental descriptions.
- The development of cognitive maps.
- The process of locomotion.

4.1 Features and Types of Cognitive Maps

The best known attempt to propose a generic structure for cognitive maps is due to Lynch (1960). It draws on the cognitive maps of cities obtained from a qualitative study of people interviewed in three US cities to propose a city image based on elements which can be divided into the five categories of path, edge, node and landmark. Lynch notes that this image is restricted to physical, perceptible objects and that images of cities may also include and be affected by the social meaning, history, function and even the name of areas, but does not include them in his model.

Paths are the channels along which people travel and include streets, walkways, railway lines, canals and tramways (Lynch, 1960). Edges are linear elements other than paths and include shores, walls and railway cuttings and act as 'lateral references rather than coordinate axes'. Districts are medium-to-large sections of the city which have a common, identifying character. Nodes are strategic spots and intensive foci to and from which the traveller is going and include junctions, crossings, points where paths come together, enclosed squares and street corners at which people gather. Landmarks are local or distant point references and include buildings, signs and shops.

The role of a particular element may depend on the circumstances and the observer. For instance, a main road may be a path for drivers and an edge for pedestrians or a central area of a city may be a district when considering the official city boundaries, but a node when the surrounding urban area is considered. However Lynch believes the categories to be stable for a given observer at a given scale and to be related to each other. He found that paths were the main city element for most of his interviewees, but that the relative importance of the different elements depended on their degree of familiarity with the city.

Appleyard (1970) has derived a de-facto model of the different types of organisation of cognitive maps based on studies of the spatial descriptions of 75 respondents of Cuidad Guyana, with the following main categories:

- Sequentially dominant:
  - i. Fragment: fragments of paths or lists of unconnected elements
  - ii. Chain: a simple, schematic map, based on a major road (which may be straightened), plus a list of places on the road.
  - iii. Branch and loop: a basically linear system based on a major road plus loops and branches representing a simplification of circuitous routes.
  - iv. Network: a relatively complete road system, possibly based on a map and sometimes schematically organised, with the rivers outlined and the road correctly located.
- Spatially dominant:
  - i. Scatter and cluster: individual buildings or establishments grouped together without any connections,
  - ii. Mosaic: the enclosure of districts by schematic boundaries and their division into subdistricts, giving the major zonal relationships, but less specific and accurate than scatter maps.
  - iii. Link: schematic linkages, which may be part of roads and between places or districts.
  - iv. Pattern: more complete and accurate, with outlines of areas and rivers as dominant features.

Lynch's model could be applied equally well to other spatial expanses, such as rural and natural/uninhabited areas. It is possible, in principle, to categorise each physical component of a city or other spatial expanse in terms of the five element types of the model, though, as Lynch (1960) notes, this classification is not unique. Further research would be required to determine whether it is the most natural or 'best' classification. The evidence obtained to date on the use of these elements in structuring the mental representations of cities seems somewhat contrived. In addition, there is a visual bias in the approach and the terminology used. In particular, the model was obtained from studies of the city images of sighted people. Though it could be generalised to blind and visually impaired people, there are differences in the subtle meanings and the relative importance of the different elements. For instance, Lynch's edges are often used as landmarks by blind and visually impaired people and to aid them walking in a straight line, but the term 'edge' is not the most suitable one in this context. In addition, there is an implicit assumption that all the landmarks are visual, whereas blind and visually impaired people will use a wide range of non-visual landmarks in addition to whatever objects and light sources they can detect visually. Furthermore, although Lynch recognises that cognitive maps will change with increasing familiarity with a city, he does not really consider the factors, such as different cognitive styles and differences in access to information, which will lead to differences in the cognitive maps of cities produced by individuals.

The first level of classification into sequentially and spatially dominant in Appleyard's de-facto model is very useful. However, the second layer classifications are derived from the organisation of a specific city and cannot necessarily be usefully generalised to other cities or spaces.

4.2 Types of Space and Environmental Descriptions

There are three main sub-categories:

- Generally de-facto models of the categorisation of space, based on 'size' and distance from the observer.
- De-facto models which link frames of reference to environmental descriptions or spatial representations.

- Formal, possibly abstract, classifications of space.

There are a number of different models of the categorisation of space, most of which are in practice de facto models rather than presented as such. The simplest is into small-scale or near space which can be seen from one vantage point and large-scale or far space which cannot and therefore requires movement to be experienced (Downs and Stea, 1977; Lynch, 1960; Ungar, 2004). Small-scale space has been further divided into A-spaces, which are smaller than the body, manipulable, viewed from one perspective and can be held, turned and rotated; and C-spaces, which include large auditoria, scenic overlooks, the horizon and the view from a plane, as well as room-size spaces that can be viewed from one point (Zubin, 1989). Large-scale space has been divided into environmental and geographic spaces. Environmental spaces require locomotion to be perceived and are learned over time through repeated experience and include buildings, neighbourhoods and cities. Geographic spaces include states, countries and the solar system and are experienced via maps, 3D models and other symbolic representations (Montello, 1993). A model of the physical space close to the body, sometimes called the primary perceptual space model (Lang, 1989) or spatial framework model (Bryant et al, 1992; Franklin and Tversky, 1992) is based on the three up-down, left-right and front-back axes. A number of studies show that this framework is used in practice (Bryant et al, 1992; Franklin and Tversky, 1990). Later models include small, medium and large-scale spaces, (Gärling and Golledge, 1987; Mandler, 1983; Siegel, 1981) with the possible addition of maps as another unique type of space which should be considered separately from the other types (Siegel, 1981).

A de-facto model, which can be derived from the work of Tversky (2000), relates three styles or perspectives of environmental description (Taylor and Tversky, 1996) to three frames of reference (Levinson, 1996) and has an additional category based on reference landmarks:

- Gaze tours, which have a single point of view, frequently an entrance and are used for small environments. They are related to the relative frame of reference which situates objects related to a person in terms of their front, back, left and right, while the gaze tour describes landmarks relative to the viewpoint.
- Route descriptions, which are used for larger environments, take the changing perspective of the traveller and describe locations to the right, left, back and front of the traveller's current position. They are an example of an intrinsic reference frame, with the traveller as the reference object.
- Survey descriptions, which are also used for larger environments, take a viewpoint from above and describe landmarks relative to an extrinsic frame of reference, frequently the cardinal directions north-south and east-west. Extrinsic reference frames are examples of absolute reference frames, which are fixed within an environment, with the cardinal directions a typical example.
- Reference landmarks, which locate a particular object as being near the target object or landmark. This has the advantage of reducing cognitive load relative to the use of reference frames, but the disadvantage of requiring familiarity with appropriate landmarks (Tversky, 2000).

Another de-facto model links two different frames of reference to spatial representations:

- Body-centred or egocentric frames of reference, which are sometimes linked to spatial representations based on routes (Millar, 1994). Body centred frames of reference may be based on the body axes (Gärling et al, 1984).
- Exocentric frames of reference, which are linked to survey or map-like representations (Millar, 1994). Exocentric frames of reference may be based on external reference axes, including streets and compass directions.

Another implicit model is based on the following categorisation of places (Downs and Stea, 1977):

- State descriptions, which are based on well-known and commonly understood coordinates, such as latitude and longitude or the intersection of two streets when the streets are arranged in a regular grid. They are generally precisely specified and unambiguous.
- Process descriptions, which are a set of instructions for getting to the particular location. They are subjective and may be ambiguous.

There are also two more formal classifications of space. Freundschuh and Egenhofer's (1997) classification has the following six classes:

- Manipulable object space, which comprises objects smaller than the human body which can be manipulated and reached without locomotion.
- Non-manipulable object space, which comprises objects bigger than the body and smaller than a house and which cannot be manipulated. Locomotion is required to view all parts of the object.
- Environmental space, of very large spaces, such as cities, states, countries and the universe, that cannot be perceived in their entirety by locomotion.
- Panoramic space of small to large spaces, that can be viewed from one point by scanning and include the view in a room and a large field.
- Map space, which gives a symbolic representation of a larger size space in a smaller size space.

Couclelis and Gale (1986) take a totally different approach based on five mathematical properties or axioms to distinguish the following five types of space:

- Physical space or the space of existence, which considers object movement as physical vectors and has the concepts of physical mass and time.
- Sensorimotor space, which combines existence and physical reaction to environmental cues.
- Cognitive space, which links environment cues to beliefs, knowledge and memory and, unlike the other spaces, is not characterised by the axioms and is free of the constraints of physical space.
- Symbolic space, which is the space of maps and other symbolic representations of space.

All these classifications have advantages and disadvantages, as well as (potential) applications, with the most appropriate classification depending on the particular application. However, not all these classifications are useful in supporting descriptions of the travel process or the underlying cognitive maps. For instance, though a formal rather than de-facto model, Couclelis and Gale's representation is too formalistic and theoretical and most of their categories are not particularly relevant to the travel process. In this context, it is probably the de-facto models with classifications into small (medium) and large-scale space or links between frames of reference and spatial representations or styles of environmental description which are the most useful. However, some of the other modelling approaches would probably be more useful in other applications.

4.3 Learning Spatial Information and the Development of Cognitive Maps

There are two models in this category, one of the information used to form spatial representations and the other of the development of cognitive maps. The information used to form spatial representations of the environment has been categorised into three classes (Péruch et al, 2000):

- Route information, which involves associations between successive perceptual images along the route or storing the route as a succession of segment lengths and turns. Route representations can be used to subsequently travel along the route, but not to find shortcuts and detours, although a dense covering of overlapping route representations would make it possible to travel between most pairs of locations.

- Path integration, which is the process of using sensed displacements and turns (Loomis et al, 1999) to update the current position. This may involve vestibular input and proprioception, possibly supported by local features of the environment and optic flow and azimuthal references, such as the sun or a mountain. Unlike route knowledge, there is minimal storage of information in memory in path integration. The currently estimated location and heading in an allocentric frame provide a simple example. The path and orientation information obtained from path integration can be used together with perceptual images of the environment to develop a representation of the spatial arrangement of different parts of the environment.
- Landmarks, with bearing and distance information from distant landmarks used to form a coherent global representation that integrates different parts of the environment.

The main theoretical framework for the development of cognitive maps or spatial representations of new environments is due to Siegel and White (1975). It has been called the ‘dominant framework’ due to its popularity and influence until the 1980s. Although it is less frequently cited now, it has not been replaced. It comprises the following three stages for both children and adults:

1. Landmark knowledge about the identities of recognisable discrete objects or scenes;
2. Route knowledge, which comprises sequences of landmarks and associated decisions, such as ‘take the first left’ and is initially nonmetric.
3. Survey knowledge in the form of a two-dimensional, maplike, scaled representation of the environmental layout and which represents the distance and directional relationships between landmarks. Its development requires routes to be metrically scaled and the relationships between them to be derived.

The categorisation of sources of information is useful, but not complete. The definition of the landmark category focuses purely on distant information, whereas information from nearby landmarks is very important for blind and visually impaired people. The use of distant information also privileges visual and to some extent audio information over other types. In addition, the de-facto model does not really explain how the different types of knowledge are used in deriving mental maps.

The main drawback of Siegel and White’s framework is the lack of convincing empirical evidence to support it and the existence of empirical evidence against it. For instance, a number of studies show that very brief exposure of the order or seconds or minutes is generally sufficient to perform tasks that require some metric knowledge at a level better than chance (Ishikawa and Montello, 2006). This implies that it is possible to develop some degree of survey knowledge very quickly and without passing through the two previous stages of landmark knowledge and route knowledge. In addition, this framework assumes that there is only one process of developing spatial representations which everyone uses, rather than that there are a number of factors which affect the process, including personal cognitive style, the circumstances and the available information. The current view is that environmental learning is not based on a sequence of landmarks, routes and configurations, but that all three types of information are learnt together, with accuracy and precision refined over time (Montello, 1993; Freundschuh, 2000).

The model also seems to be based on the tacit assumption that survey representations are the goal to be aimed for and superior to the other two types of representation, rather than recognising that the most appropriate type of model will depend on the particular application. Individuals probably use different types of spatial representations in different applications, but empirical investigation will be required to determine whether this is in fact the case. There are some indications, though further research is again needed, that many blind people develop route rather than survey representations, both because they are sufficient to meet their needs and because they lack access to the information which would be required to produced a survey representation. People may also develop route rather than survey representations, because their main interest is in travelling between places rather than detailed knowledge about their surroundings.

4.4 The Process of Locomotion

Two main models of the process of locomotion by blind and visually impaired people have been developed. Both these models focus on individual journeys and do not consider the (route) learning which results from each trip. Brambring's (1985) model is hierarchical with two main levels. Although Harper et al's (2002) model is to some extent sequential with eight main stages, the stages are not totally independent of each other and some looping back to previous stages occurs. They consider their model a 'flow of travel' and compare it to the flow and looping characteristics of computer control programs.

Brambring's (1985) model (see Figure 1) has two components at the first level, namely 'perception of objects' and 'process of orientation'. At the second level perception of objects has the two aspects 'detection of obstacles' and 'identification of landmarks', with a two-way link between them, as well as from identification of landmarks to process of orientation. Process of orientation has the two second level aspects 'spatial orientation' and 'geographical orientation', with a link from spatial to geographic orientation. Spatial orientation is defined as the ability to estimate position relative to the immediate surroundings and can be used, for instance, to determine the optimum position on the pavement. Geographical orientation is defined as the ability to determine position relative to topographic (distant) space and is required for wayfinding in an unfamiliar area.

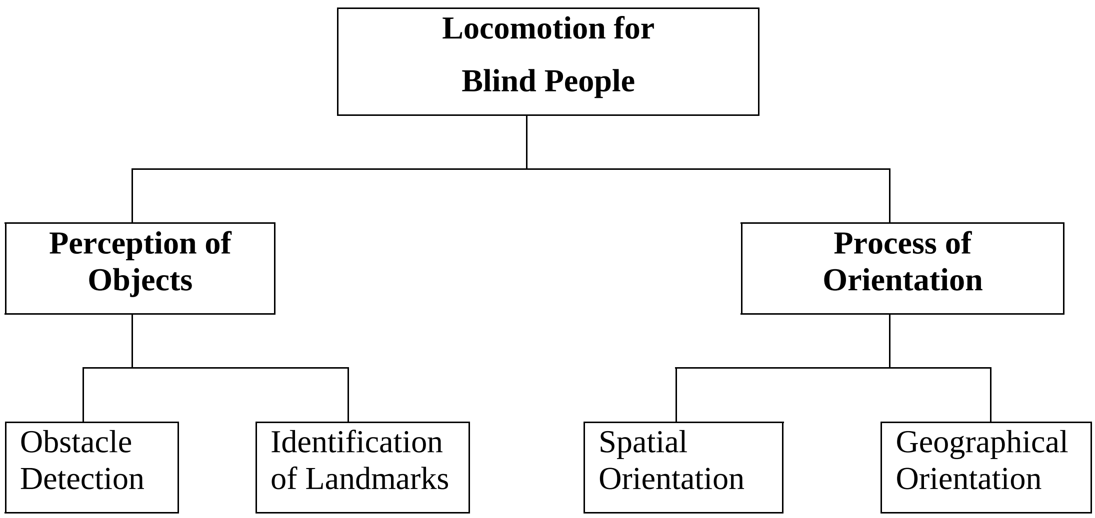

Figure 1, Brambring's model of locomotion by blind people

Brambring considers that the abilities to detect obstacles, identify landmarks and carry out spatial and geographic orientation are all essential for independent travel and that moving towards a destination generally involves moving between landmarks, with blind people generally requiring a large number of landmarks to learn a route. He suggests that travel involves determining the pattern of objects and locations relative to landmarks, with effective landmarks being stationary and easily identifiable under varying environmental conditions, such as changing noise and weather. Brambring considers the detection of obstacles to involve perceiving them in time to avoid collisions, with particularly dangerous obstacles including down steps, low lying and fast moving obstacles. However, he recognises that the distinction between obstacles and landmarks is not well defined and that objects such as trees, parking meters and steps can be both obstacles and landmarks or become landmarks with familiarity.

Harper and Green's (2002) model comprises eight main tasks, supplemented by a graphical commentary, which organises navigation and orientation objects as memories, obstacles and cues with a set of associated actions linked to a method with a number of associated properties. For instance, the Journey task requires obstacle objects to be detected and does this using preview and probing methods which provide specific and detailed information about the object to enable it to be avoided. The model distinguishes between waypoints, which may be arbitrary points, such as junctions, or designated waypoints with, for instance, audio markers; information points which provide complex information such as a timetable or map via an appropriate device; and orientation points, which the authors do not define.

The eight main stages of Harper and Green (2002)'s model are:
1. Aim or aimlessness
2. Pre-plan journey
3. Decide on start and end points
4. Journey
5. Keep to track
6. In-route guidance
7. Move to next point
8. Achieve next point.

Looping back occurs from Achieve next point to Journey, from Move to next point to Keep to track and from Keep to track to Aim or Aimlessness. Harper and Green (2002) propose that the environment needs to be updated to give appropriate cues and explicit feedback to make up for the lack of visual feedback. They consider orientation to require knowledge of the basic spatial relationships in the environment and navigation the ability to move in the local environment. Thus navigation requires preplanning with the help of maps or previous knowledge or obtaining information about immediate objects and obstacles, ground formation (such as stairs and holes) and moving and static obstacles while travelling, as well as mapping and knowledge storage. (Harper and Green, 2002) consider cognitive mapping to involve the collection, organisation, recall and manipulation of information about the everyday spatial environment to obtain knowledge about where to go and how to get there. They suggest that the mental maps of visually impaired people are generally egocentric, exact and divided into smaller more manageable stages, with body rotation used to describe parts of a journey. They consider the route descriptions of blind people to be more complex than those of sighted people, with more specific and more detailed information about obstacles. However, they seem to ignore the fact that most travel by blind people is very much goal driven and in response to a need to go somewhere specific, rather than resulting from deciding whether or not to go somewhere and considering possible destinations.

As already indicated the main problem with both these models is that each trip is considered as a totally isolated incident, separate from both other trips and the context in which the trip takes place. In particular they do not allow for learning and the process by which unfamiliar routes become familiar and which is particularly important for blind and visually impaired people, who will frequently only travel familiar routes on their own. These models also do not consider the factors which motivate and/or enable blind and visually impaired people to decide whether or not to take a trip or the factors which determine whether they are able to make the trip on their own or require an accompanying person. The models do not consider choice of mode of transport for either the whole journey or parts of it and there seems to be an unstated assumption that the whole journey will take place on foot. While pedestrian travel is important for blind and visually impaired people, many of their journeys involve some form of transportation and a model of the travel process should be able to include such journeys.

Brambring's model has the advantages of simplicity and clearly indicating the main activities involved in travelling on foot of detecting and interpreting objects as landmarks or obstacles and maintaining orientation relative to both the immediate and wider environment. However, it does not consider decision making on whether or not to travel or planning prior to travel, for instance obtaining information about where the destination is and choice of route. While it is indicated that the orientation component involves a process, the model leaves it to be assumed that the object perception component also involves a process and does not describe the process in the case of orientation or indicate whether it is continuous or involves a series of one-off, but possibly connected events. The model also presents a much greater distinction between orientation and obstacle avoidance than is generally the case in practice, and the description of walking straight is not appropriate for blind people.

Harper et al's model is more complex than Brambring's, but this greater complexity allows a more detailed consideration of the processes involved in travel. In particular the flow approach is able to model the interaction between the different travel tasks and the cyclic or repetitive nature of the process. Although the model does not make this totally clear, the Keep to track task may allow consideration of what happens when a person becomes disorientated or strays from the desired route, whereas Brambring's model is not specific or detailed enough for this type of consideration. Harper et al consider that the model can be used to facilitate identification of the need for additional travel aids to support particular components of the travel process. Their model also includes a pre-planning task, which includes references to physical and mental maps, as well as past journeys. However, it does not explicitly include asking other people for information and directions, which is a relatively frequently used means of obtaining information for blind people, particularly when travelling on unfamiliar routes, or the use of timetables in an appropriate format, as would often be required for the use of public transport. In addition, they provide a purely visual representation of their model and the nature of the model makes it difficult to obtain a satisfactorily representation of it in purely textual format. The form of the model consequently not accessible to many blind and visually impaired people.

5. Travel Model

The discussion in the previous section has shown the scarcity of models of the travel process, as well as the limitations of existing models. One of their greatest drawbacks is the fact that they generally only cover one component of the travel process, such as the components of mental images of cities, the process of learning and updating mental representations, or a specific journey, rather than the whole process. Many of the models (or model components) relate specifically to either blind or sighted people rather than covering the whole spectrum, with appropriate modifications to take account of any significant differences in the travel processes of blind, visually impaired and sighted people. Many of the existing models also have a number of limitations even when considered only in terms of their intended application(s) rather than as a model of the whole travel process.

There is therefore a need for a model of the whole travel process, which is flexible enough to cover blind, visually impaired and sighted people. This can best be achieved by using a modular structure comprising a number of separate components with links between them. The model uses the following three main component models:

1. The cognitive or mental map of space (with reference to travel)
2. The process of obtaining or updating the mental map of a particular space.
3. The travel process i.e. the activities which take place on a particular journey or trip.

There is then a cyclical relationship between these three components, which reflects the real process by which routes and areas are learnt and go from being unfamiliar to becoming familiar. In particular, as shown in Figure 2, the activities on a particular journey feed into the process of learning or updating the cognitive or mental map. This then leads to updated knowledge of the particular route and/or the surrounding space. This updated knowledge (modified mental map) then affects and facilitates subsequent travel on this route and may also affect other journeys.

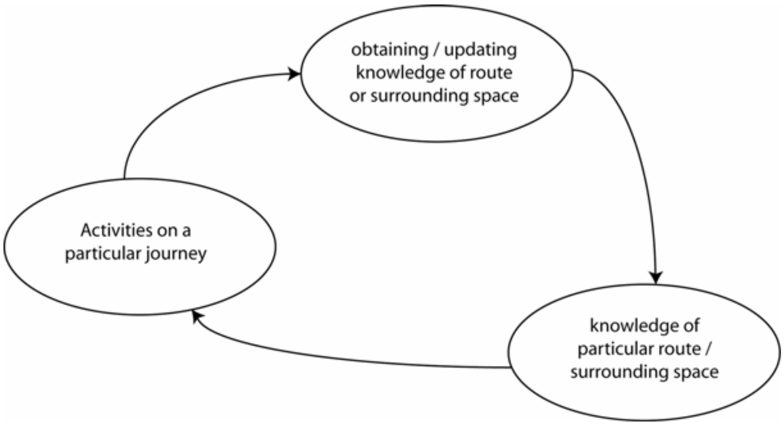

Figure 2, Process of route learning by which unfamiliar routes become familiar

This process is then reflected in the cyclic relationship between the three model components, which is shown in Figure 3. Thus, the model of the travel process (component 3) feeds into the model of the process of learning or updating the cognitive map (component 2). This then leads to modifications of the cognitive or mental map of space (component 1). This modified mental map will then feed into the travel process and affect subsequent travel.

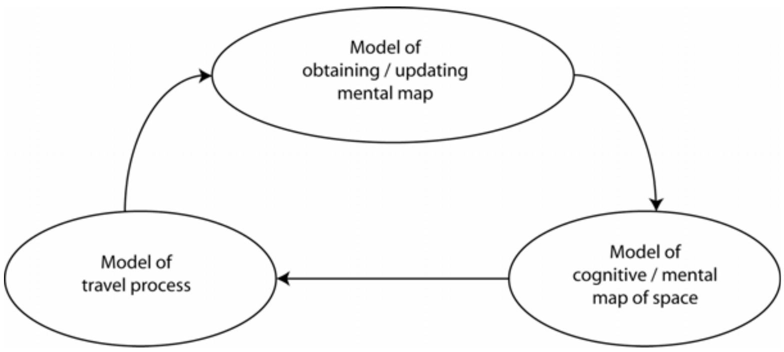

Figure 3, Three-component model structure

In the case of blind and visually impaired people, the difference between familiar and unfamiliar routes and areas and, consequently, the process by which spatial representations of routes (and areas) are obtained and updated is particularly important. While this difference is not quite as significant for sighted people, it is still important. However, it should be noted that a cognitive or mental map of space is to a certain extent a construct, which is intended to represent the way in which people store spatial information and represent it to themselves.

Travel involves basically the same processes for blind, visually impaired and sighted people, though they do not always carry out these processes in the same way. In particular, blind and visually impaired people have different sources of (sensory) information, use different types of landmarks and more frequent landmarks and currently find many sources of environmental information inaccessible. In addition, they generally require a much higher degree of attention and concentration in order to travel and experience considerably more fatigue. It should also be noted that there are also differences between individuals, some, but not all, of which are a consequence of factors such as gender, age and culture. However, the underlying similarities in the process make it meaningful to draw up a unified model for all travellers.

The following three sections provide an overview of the three components of the model and relate them to existing research. The model details, which are not presented are likely to be modified as a result of subsequent research and validation.

5.1 Cognitive or Mental Maps of Space

This builds on the work of previous researchers and extends it. The focus is on cognitive or mental maps which can be used in travel, including inside a building, building complex or under a covered area. There are three main types of mental models of space of relevance to travel:

- Salient features map
- Route maps
- Overview, gestalt or survey maps

The term salient feature map has been coined to describe mental maps which focus on one or more salient features, which may be all close together or spread over a wide area, but provide little information on the spatial relationships and route connections between the different features. There is some similarity with the landmark maps referred to in the literature (Pérach et al, 2000; Siegel and White, 1975; Tversky, 2000), but the term salient feature is preferred here, as the focus is on objects as features of importance e.g. a particular building being visited and these features may or may not also serve as landmarks, depending on how distinctive and easy to detect they are. Models of this type are frequently generated for relatively unfamiliar areas.

Route maps generally comprise one or more routes. Routes are divided into route segments (Cornell and Heth, 2000) which are defined as the natural components into which routes are decomposed by travellers. A given route segment may comprise the section of a route that the particular traveller can remember at one time or the route segment between two decision points. The mental model or description of a route segment generally contain the information required by the particular traveller to successfully travel along it and is generally considerably more detailed for blind than sighted travellers. The details of the information chosen and how it is encoded will depend on a number of factors, including personal cognitive style and whether or not the individual is visually impaired. It is hypothesised that route segment information includes the following main components:

1. A division into sub-segments.
2. The sub-segment start and end points, which are generally decisions points, such as road junctions or road crossings.
3. Objects, namely landmarks and/or obstacles, which are used to verify that the traveller is remaining on course, avoid collisions and to provide information as to where they are on the route and how far they still have to travel.
4. Shorelines, such as walls and curbs, which are used by blind and visually impaired people in particular to ensure that they remain on the appropriate path and do not veer or weave.
5. The information required to follow the route, in particular road junctions, road crossings and other decision points and the action to be taken at them.

Landmarks and obstacles are primarily sensory, whereas route (segments) and shorelines are sensorimotor (Siegel and White, 1975). As noted by a number of authors e.g.

(Brambring, 1985), the distinction between landmarks and obstacles is not clearly defined and an object can act as both or change from an obstacle to a landmark with increasing familiarity. Obstacles are generally included in the route maps of blind and visually impaired people, but rarely those of sighted people. While the landmarks used by sighted and some visually impaired people will be largely visual and constant, those used by blind and other visually impaired people will draw on information from touch, hearing, smell and possibly vision and some of these landmarks may only be perceptible at certain times of the day, week or year. As well as using different types of landmarks from sighted people, blind and visually impaired people also use a significantly greater number of landmarks.

Drawing on and extending the work of Appleyard (1970) the following structured categorisation of survey maps is proposed:
Level 1
- Sequential, based largely on roads, routes and possibly also rivers.
- Spatial, based largely on districts, landmarks and rivers.

Level 2
- Non-schematic
- Schematic

This gives four main categories. Within each of these categories different degrees of detail and accuracy are also possible. At the highest level of detail (and accuracy) there is probably considerable convergence between sequential and spatial maps.

5.2 Model of Learning and Updating Cognitive Maps

This describes the process by which unfamiliar routes and areas become familiar. This is particularly important for blind and visually impaired people, but not unimportant for sighted people. It is postulated that the relationship between route and survey map representations is different for different people and further research would be required to investigate the factors on which this relationship depends. Therefore the model is presented for route and/or survey maps and does not include details of which order they develop in or the transformation of a route into a survey map or vice versa.

The degree of detail in the mental map will depend on both individual and circumstantial factors, including whether and how frequently the person is likely to travel along the route or in the area. The process of developing a model involves the following five stages:

1. Obtaining preliminary information: The degree of detail at this stage varies and this information can be obtained either prior to or during travel or both

2. Encoding the information to form a route and/or survey map framework. The details of the encoding, as well as the extent to which the framework is committed to memory, vary between different individuals.

3. Obtaining more complete and/or more detailed information: This involves obtaining the further information required to develop the framework, fill in the details and correct errors.

4. Mental map: This involves incorporating the additional information into the existing framework to form a mental map and establishing the map more firmly in memory.

5. Revising and updating the mental map: This involves comparison, possibly unconsciously, of the mental model with the actual route and/or surrounding area, adding new information and revising and recoding the model to take account of changes. It may also involve referring to sources of information to fill in additional details.

5.3 Model of the Travel Process

This model draws on the two main previous models due to Harper et al (2002) and Brambring (1985). It is divided into three main modules: pre-travel, walking and using public transport. Each module has a number of steps, as well as a description of the factors that affect whether the step is carried out and/or a description of how the step is carried out. The steps in the walking module are carried out repeatedly until the end of the pedestrian segment is reached and will then be repeated on the next pedestrian segment, whereas those in the public transport module are repeated for each change of vehicle.

A Pre-Travel

1. Decision about whether to travel. This depends on the type of journey and other factors, some of which are specific to the type of journey.
2. Pre-travel: planning:

3. Got to B1 or C1.

B Walking

1. Determine the correct direction to walk in.

2. Walk along a route sub-segment and carry out a number of activities while walking.

3. Reach destination or a road crossing, decision point or obstacle that requires a detour.

4. Continue walking toward next subsection decision point or road crossing.

C Public Transport

1. Locate point of departure e.g. bus stop or railway station.

2. Obtain formal or informal assistance, if required.

3. Activities at point of departure.

4. Vehicle entry and in-vehicle activities.

5. Vehicle exit activities.

6. Go to B1 or C1.

5.4 Validation of the Model

The three-part structure of the model draws on the distinction between familiar and unfamiliar routes, as well as other factors derived from the author's empirical research and a study of the literature. This distinction is particularly important for blind, deafblind and visually impaired people. The model takes account of this fact through the three components of a cognitive or mental map or representation of knowledge about routes, learning the cognitive map and the travel process.

However, further empirical research will be required to fully validate the model. This empirical research will have the following two main components:

- Testing a number of hypotheses derived from the model using a series of studies of the travel and spatial behaviour of blind, visually impaired and sighted people.

- The development of applications of the model and investigation of the validity and usefulness of the models with regards to these applications.

It is probable that the process of model validation will lead to modifications of the model, possibly of significant components and not just some details.

6. Conclusions

A body of work has been developed on the travel processes of blind, visually impaired and sighted people as well as the underlying cognitive maps. However, to date a universally accepted model of the travel process, which is applicable to blind, visually impaired and sighted people has not been developed.

The tutorial commenced with a review of the literature and a critical discussion of the existing models. These were divided into the following four categories, each with two or three sub-sections:

- Types and features of cognitive maps:
  - ♦ Lynch's (1960) five component model of the cognitive maps of cities
  - ♦ Appleyard's (1970) two-level model of the organisation of cognitive maps of cities
- Types of space:
  - ♦ Generally de-factor models of the categorisation of space, based on 'size' and distance from the observer.
  - ♦ De-facto models which link frames of reference to environmental descriptions or spatial representations.
  - ♦ Formal possibly abstract classifications of space.
- Learning space and environmental descriptions:
  - ♦ Péruch et al's (2000) model of the type of information used in deriving cognitive maps.
  - ♦ Siegel and White's (1975) dominant three-stage framework of the development of cognitive maps of space.
- Process of locomotion
  - ♦ Brambring's (1985) two level hierarchical model.
  - ♦ Harper and Green (2002) eight-stage travel flow model with looping back to previous stages.

All these models have advantages and disadvantages, as well as areas of application. However, one of the greatest drawbacks of all the models is the fact that they generally only cover one component of the travel process, such as the components of mental images of cities, the process of learning and updating mental representations, or a specific journey, rather than the whole process. Many of the models (or model components) relate specifically to either blind or sighted people rather than covering the whole spectrum, with appropriate modifications to take account of any significant differences in the travel processes of blind, visually impaired and sighted people. In addition, several of these models also have a number of limitations even when considered only in terms of their intended application(s) rather than as a model of the whole travel process.

Other than in the case of some of the de facto models, most of the models lack any indication as to whether they are intended to be idealised models or real models of how people actually travel or represent space. Many of the models lack an empirical validation. Where empirical evidence does exist, it does not always support the models, as in the case of Siegel and White's model, where the evidence indicates it is flawed, or supports the principles, but is more ambiguous on the details, as in the case of Lynch's model, where the available evidence seems to point to a number of common elements in the representations of cities, but is less clear as to whether Lynch's choice of elements is the most appropriate one and whether it is actually used by a significant number of people.

This has motivated the development of a new model, which covers the whole travel process and is flexible enough to cover blind, visually impaired and sighted people. This can best be achieved by using a modular structure comprising a number of separate components with links between them. The model uses the following three main component models:
1. The cognitive or mental map of space (with reference to travel)
2. The process of obtaining or updating the cognitive map of a particular space.
3. The travel process i.e. the activities which take place on a particular journey or trip.

In addition to giving a modular structure for modelling the travel process, this approach has the advantages of explicitly modelling the process by which unfamiliar routes and areas become familiar. The difference between familiar and unfamiliar routes is particularly significant for blind and visually impaired people, but not without importance for sighted people.

However, it should be noted that the model is very much a work in progress. It provides a framework with a number of applications, including the following:
- Testing and modifying hypotheses about the travel process and spatial understanding,
- Supporting further work on investigating the factors that support independent travel by blind and visually impaired people and what measures are required at an individual and societal level to improve their mobility.
- Supporting the classification of the different approaches to travel and different types of travel processes used by different groups of people and the factors which determine which type of travel process a particular individual or group of people prefers or finds most appropriate.
- Investigating the match between current assistive technology provision and the travel process and determining where there are gaps and which stages of the travel process required additional assistive technology or more accessible environments.

It is likely that the associated empirical research will lead to possibly very significant modifications of the model framework and that the final validated model may be very significantly different from the current version. In addition, empirical research will have the following further applications:
- Separating the components of the model which are of purely theoretical interest as part of an idealised travel process and those which describe the actual travel behaviour and spatial representations of real blind, visually impaired and sighted people.
- Obtaining submodels or identifying particular model components which are relevant to particular, but not all groups of travellers.

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