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Cognitive Mapping without Visual Experience

Simon Ungar

INTRODUCTION

Try this simple experiment: close your eyes tightly, stand up, and walk to the other side of the room and back. You have just simulated for yourself what it is like to be blind. Well, not quite: there are several important factors missing. Firstly, you knew all along that you could open your eyes at any minute if you ran into trouble (e.g., a large hard obstacle). A blind person does not have that option for recovering from a mistake. Secondly, you almost certainly used your visually derived mental 'map' of the room's layout to guide you. Think how much harder it would have been to do the same thing in an unfamiliar room. Thirdly, you drew on a set of spatial concepts and orientation skills developed across your life-span that involved vision as a major unifying sense; the very first time you, as an infant, watched your hand as you reached out for an object, you were already learning about space through vision.

Even this experiment hardly brings you close to the everyday experience of someone who is totally, congenitally blind. Such a person has no visual memories of particular spaces, and has had no direct *visual* input into the development of their spatial understanding in general. Their experience of space comes from hearing, touch and movement, and yet they can engage in pretty much all the activities that a sighted person can. How is this possible when we, as sighted people, place so much importance on visual experience in our lives? Through theories and research in cognitive psychology and behavioural geography, this chapter will explore the way(s) in which blind people experience and represent space. The first section will trace the history of thinking on the subject, the second will assess current work while the third will look to the future.

THE PAST: GETTING THE QUESTION RIGHT

What is it about vision that makes it so well suited for spatial representation? A number of features of the visual system make this modality appear to be better suited to spatial information than any other (Foulke and Hatlen, 1992; Millar, 1994; Thinus-Blanc and Gaunet, 1997). Vision provides relatively simultaneous perception of a large spatial field: although the point of foveation is quite limited, other objects are still present in peripheral vision as our attention wanders round a particular scene. In a sense, haptic exploration is like foveation without peripheral vision, in that the positions of objects not currently being attended to must be maintained in memory and no cues are available to draw attention in any particular direction. Vision is more precise than audition both in terms of accuracy of localisation (distance and direction information) and identification of objects (features that tell us what something is). These advantages of vision for spatial perception have often led theorists to assume that blind and visually impaired people must necessarily be deficient in spatial abilities.

The spatial understanding of blind people became a topic of study in the late 17th century, when the English philosopher Locke attempted to answer a question put to him by his friend Molyneux:

> Suppose a man born blind, and now adult, and taught by his touch to distinguish between a cube and a sphere of the same metal, and nighly of the same bigness, so as to tell, when he felt one and the other, which is the cube, which the sphere. Suppose then the cube and sphere placed on a table, and the blind man be made to see: quaere, whether by his sight, before he touched them, he could now distinguish and tell which is the globe, which the cube? (Locke, *An Essay Concerning Human Understanding*)

Locke's answer to this question is negative. As an empiricist, he believed that our minds originate as a 'blank slate' (*tabula rasa*) and that all concepts we have are derived from our sensory experiences. Thus a congenitally blind person would only have *tactile* impressions of objects, and these could not automatically allow him to recognise the same objects by sight. It is only by integrating experiences from different senses that we build up abstract (amodal) concepts. In contrast to Locke, rationalist philosophers argued that abstract ideas about the world (including spatial concepts) are present at birth: we recognise something as spherical, in any sensory modality, by matching it to a pre-existing concept of a sphere.

The dichotomy of empiricism versus rationalism has continued to influence theories of the mind in the form of the famous 'nature/nurture debate'. However Millar argues that this way of thinking about the problem offers us little in either theoretical or practical terms (see Millar, 1994, for a fuller discussion of this issue), and she suggests an alternative reading of the question, focusing on the empirical issue of how perception relates to knowledge. In other words, if one perceptual modality (i.e. vision) is missing, what (if any) effect does this have on our knowledge of the world? Here, the question is phrased in terms of information processing and directs us to a study of the nature of information handled by the various modalities, the way this information is processed and the way the resulting representations guide or influence spatial behaviour.

Logically, three answers have been proposed for this question (Andrews, 1983; Fletcher, 1980): the lack of visual experience may result in a total lack of spatial understanding (the 'deficiency' theory); it may result in spatial abilities which are similar to, but necessarily less efficient than, those of sighted people (the 'inefficiency' theory); or it may result in abilities which are qualitatively different from, but functionally equivalent to, those of sighted people (the 'difference' theory).

The first of these positions is exemplified by the work of von Senden (1932) who argued that spatial concepts are impossible in people who have been blind from birth, and that visual experience during some early period is essential for even a minimal understanding of space. This strongly empiricist position is based on the assumption that vision is the sense through which all spatial representation is derived. More recent work has undermined this position, as Von Senden's methods have come under critical scrutiny and as empirical evidence has accumulated which goes against his position.

It has proved considerably more difficult to distinguish between the inefficiency and difference theories, with much of the empirical evidence supporting either theory. This is because most studies have simply focused on current spatial abilities (competence) rather than on potential, for instance by looking at gross performance on spatial tasks without considering the specific representations or strategies underlying performance. More recently, some authors (Millar, 1994; Thinus-Blanc and Gaunet, 1997; Ungar *et al*., 1995b; 1996a; 1997a) have begun to focus explicitly on the strategies used to solve spatial tasks and the relationship between these and spatial performance. If the poor performance of blind groups on spatial tasks is due to a necessary limitation imposed by the lack of vision on the range of strategies they can use to code spatial relations, this would support the inefficiency theory. If on the other hand it can be shown that blind people potentially have access to a range of strategies, some supporting excellent performance, then this would favour an explanation in terms of difference. Indeed, Millar's (1994) approach challenges the very relevance of explanations phrased in terms of differences between blind and sighted people in the processing of spatial information. She places all the emphasis on the information that is available to people under particular task conditions (e.g., blind versus sighted task conditions). We will return to these more recent approaches after a review of the literature.

THE PRESENT: EMPIRICAL EVIDENCE AND THEORETICAL FRAMEWORKS

Some Important Distinctions

Near Space vs. Far (Haptic vs. Locomotor) Space
In research on spatial cognition in blind and visually impaired people, a distinction is usually drawn between 'near' and 'far' space. The former relates to small-scale or manipulatory space: areas that can be explored without changing the location of the body. The latter relates to medium- or large-scale space: areas in which locomotion is required for exploration. Although the main focus of this chapter is on the latter, research on small-scale spatial tasks in blind children tells us a lot about the nature of spatial representation in general.

In the absence of vision this distinction is very important for the performance of spatial tasks. In small-scale space, where haptic exploration with the hands and arms is used, object locations can be represented relative to one's own body, providing a stable egocentric frame of reference. In large-scale space where exploration involves locomotion, the body must translate (i.e. change location), and egocentric reference frames become less reliable.

Millar (1994) points out that vision provides at least three advantages for the sighted traveller: the coincidence of body-centred and external reference frameworks during locomotion; the ability to look forwards and backwards along a route and thus integrate the locations of spatially separated landmarks; and in terms of prior knowledge about coding the relations of planes and surfaces. Thus, despite some logical similarities between blind and sighted people's experiences of large-scale space, there are some important functional differences also.

Early vs. Late Onset

In considering the understanding of space by blind people it is important to make a clear distinction between people who have been blind since birth or early in life, and those who have lost their sight later and have therefore had some visual experience. Exactly how long a period of visual experience is necessary or at least valuable for spatial development? In general, the performance of later blinded people on a range of spatial tasks is more similar to that of sighted people than of early blind people. However, studies have employed widely varying cut-off points for the distinction between early- and late-blindness, ranging from a few months to three years of age. Although the results remain interesting for theoretical purposes, it will be necessary to be more precise about this factor in future research.

Memory versus Inferential Tasks

Another important distinction is between tasks that require participants to make a response based on a spatial relation that has been directly experienced, and tasks that require participants to infer a new relation based on their direct experience. The former simply requires some form of spatial coding, while the latter requires that a transformation be performed on the coded information. This distinction has frequently been used to test for differences in spatial coding particularly in large-scale space where performance in inferential tasks is generally more efficient and reliable when based on external coding, for instance an integrated or 'map-like' representation of a spatial layout.

On the Table Top: Coding Strategies in Haptic Space

Coding Spatial Relations

In performing any spatial task, one has the option of coding the location of an object either by reference to one's own body and/or movements, or relative to some external framework (see Tversky, this volume, for a detailed discussion of this topic). For instance, I can determine the position of a cup on my desk either by its distance and direction from where I am sitting (i.e. by extending my arm by a certain amount in a particular direction relative to my body) or by its position relative to the layout on my desktop (e.g., between the computer and the lamp). Either method should allow me to reach for it accurately (all other things being equal!). A number of studies have focused on the way blind and sighted people spontaneously code the locations of objects in small-scale space (for a detailed review of these studies, see Millar, 1994).

Generally, such studies show that people with little or no visual experience (congenitally and early blind) tend to code spatial relations in small-scale space by reference to their own body co-ordinates and/or their arm movements during exploration of the experimental space. According to Millar (1982), this is because the 'type and reliability of spatial information' (p. 72) available under blind conditions differs from that available with vision, and these differences in the quality of experience generally prompt early-blind children to organise spatial information by different coding strategies from those that tend to arise from visual experience.

Consider, for instance, the task of repeatedly locating a cup of tea placed in a constant position on a desk as you remain seated at the desk, also in a constant position. With vision, it may be more natural to code the cup's position relative to other objects on the desk. In the absence of vision, this strategy would involve locating the reference objects by touch each time you wanted to take a sip. It would be far more efficient in this case simply to encode the cup's position relative to your own body co-ordinates or according to a reliably reproducible series of arm movements. A similar everyday example comes when we are sitting in a stationary train, and an adjacent train starts to move off. Initially we feel, on the basis of visual information, that our own train is moving, but kinaesthetic information soon tells us the truth. Here, visual information is clearly *less* reliable than kinaesthetic information.

In this sense, strategies are seen by Millar as 'optional forms of coding' which differ in the types of information selected (e.g., relationships between locations in space or relation of locations relative to the body mid-line) and the coding heuristics appropriate for a particular type of information (e.g., external frame of reference, self-referent, movement). The strategies are optional in the sense of being interchangeable, although they are not necessarily equally reliable in a given context (e.g., the moving trains example). Visual experience prompts children to attend to external cues (e.g., the interrelationships between locations) and this is the case both for sighted children performing the tasks blindfold and for late-blinded children. Congenitally blind children tend to neglect such cues and thus adopt different strategies.

These strategies produce reliable performance in most small-scale tasks, the chief exception being those that involve spatial inference or mental rotation. In these cases the cognitive load involved (in calculating a new spatial relation or updating spatial relations after rotation) is greater with body-centred and movement strategies, although it is not impossible. If external cues are attended to and used, however, performance is generally improved. Such external cues are potentially available even in the absence of vision.

This is supported by a study (Ungar *et al*., 1995b) in which blind and partially sighted children were asked to examine and then reproduce a layout of shapes either from the same location or at a new location, 90° rotated around the display. In the analysis, the children's exploration strategies were examined in relation to their performance in the reproduction task. The analysis showed that children who adopted a strategy that related objects to each other and to the frame of the display were less affected by the rotation than children who learned the objects' locations by simply touching each one repeatedly. It seems likely that these exploration strategies were correlated with particular coding strategies: children using the former strategy probably coded each object location by reference to the rest of the display while children using the latter strategy probably coded object positions relative to their body and/or arm movements. Similar results were found more recently by Gaunet et al. (1997).

External cues also become advantageous when the task is very complex. Ungar *et al*. (1997a) asked early-blind and sighted participants to learn a complex map of a fictional town, and then to reconstruct it from memory. Performance of the blind group was significantly poorer than that of the sighted group. However, the large individual differences within the blind group were accounted for by the various strategies used to explore the map and organise the information. Better performance was associated with strategies that took used external reference frameworks, and it is likely that such strategies were used by participants who had more experience of small-scale spatial tasks, such as reading tactile maps or using the Optacon.

Summary

Spatial tasks at the small-scale (as we have defined it) are generally performed well by early-blind participants relative to late-blind and sighted groups (Millar, 1994; Thinus-Blanc and Gaunet, 1997). Lack of visual experience tends to give rise to body-centred and/or movement based coding strategies as these are generally more reliable at this scale under blind conditions, and generally prove to be functionally equivalent to those used by sighted people (Klatzky et al., 1995). Such strategies prove less effective when tasks require mental reorganisation, mental rotation or spatial inference, or when tasks are very complex. However congenitally and early blind participants do have the potential to use externally based coding strategies which support good performance even on these tasks.

Wayfinding and Cognitive Maps: Locomotor Space

Methods of Externalising Cognitive Maps

A similar range of methods has been used to investigate the cognitive maps of blind people as has been used with sighted people (see Kitchin, 1996, and this volume, for a review). Sketch mapping is not widely used as blind people are generally unfamiliar with this medium, but the construction of models is used. More common have been direct (re)production of a route, distance or direction by walking, distance estimation or direction estimation using some kind of pointer. The relative reliability and validity of these measures for blind people has been considered in a number of studies (Haber *et al*., 1993; Kitchin and Jacobson, 1997; Morsley, 1989).

Familiar Environments

By looking at spatial knowledge of familiar environments, we can investigate the structure of cognitive maps constructed over time in relatively large areas. It is generally impractical to familiarise participants with very large and complex areas due the time consuming nature of this process.

Casey (1978) asked blind and sighted schoolchildren to produce a plan of their school campus using model buildings. He found that the blind participants as a group were less accurate than sighted participants, but that some individual blind participants were very accurate. Casey also found that the performance of blind participants was correlated with their level of independent mobility, although the direction of causation was not explored. In an analysis of the models produced by Casey's participants, Golledge *et al*., (1996) pointed out that the congenitally blind participants had a tendency to linearize curved paths, that the maps were segmented and chunked rather than integrated and that features on familiar routes were more accurately represented than those on less familiar routes.

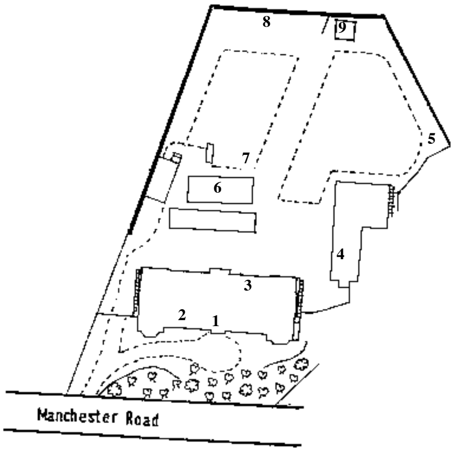

Figure 1: Layout of the school and grounds used to test children's knowledge of a familiar environment by Ungar (1994, Experiment 3) 1 - Entrance steps, 2 - Dining room, 3 - Staff room, 4 - Assembly hall, 5 - Skittle alley, 6 - Play area, 7 - Sand pit, 8 - Boat, 9 - Swings.

Ungar *et al*., (1996b) asked eighteen visually impaired children (aged 6 to 12.5 years) to estimate distances between nine locations around their school (see Figure 1). Rank order correlations were performed to compare the distance judgements of each age and visual status group with an accurate set of Euclidean and an accurate set of functional distances[1]. On the whole, children's relative distance judgements correlated more highly with the functional baseline than with the Euclidean baseline. In order to gain some impression of the mental representations underlying children's relative distance judgements, the data were analysed using multidimensional scaling. For all participants taken together a picture emerged in which functional distances were exaggerated, and these functional distances were based on habitual paths of movement by the children in their daily school activities. Overall the results were consistent with those obtained with adults by Rieser *et al*., (1980).

Constructed Environments
One problem in testing people's knowledge of familiar environments is that it is impossible to control for individual differences in experience. Therefore a number of studies have tested children in novel environments - either an experimental environment constructed in the laboratory (Fletcher, 1980; Landau *et al*., 1984; Rieser *et al*., 1982; 1986) or an unfamiliar part of the real world (Dodds *et al*., 1982; Espinosa *et al*., 1998; Leonard and Newman, 1967; Ochaíta and Huertas, 1993)

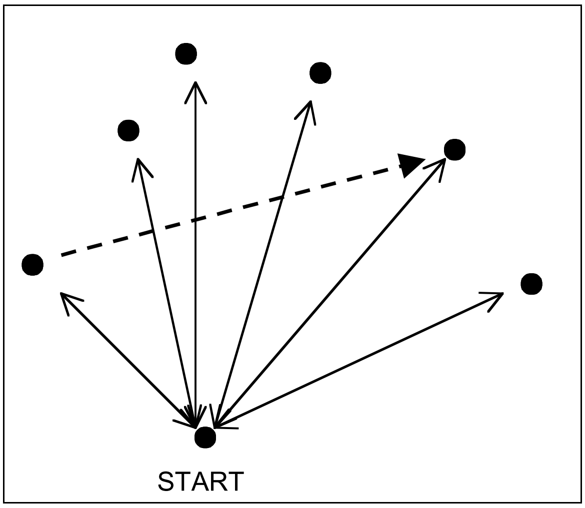

Figure 2: Layout used by Rieser, Guth and Hill (1982; 1986, based on a diagram in Thinus-Blanc and Gaunet 1997). Solid arrows represent paths used to learn layout. Dotted line shows one example of an inferred path

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[1] Euclidean distances are direct or 'crow's flight distances. Functional distances are actual travelling distances or 'city block' distances.

Rieser *et al*. (1982; 1986) tested the ability of congenitally totally blind, later blinded and blindfolded sighted adults to keep track of their position relative to a number of landmarks as they moved or imagined moving through an experimental layout of objects (see Figure 2). The participants learned the layout by walking with an experimenter from the start point to each of the landmarks in turn, returning to the start each time. The participants were then tested in two experimental conditions. In the locomotion condition, participants were led by a circuitous route to one of the experimental landmarks and asked to aim a pointer at each of the other landmarks in turn. In the imagination condition participants made pointer estimates from the start point but were asked to imagine that they were standing at one of the experimental landmarks.

The sighted and the adventitiously blind groups performed very accurately in the locomotion condition but less accurately in the imagination condition. In contrast, the performance of the early blind group was similar in both conditions to the performance of the other groups in the imagination condition. Furthermore, the response latencies of the sighted and adventitiously blind were longer for the imagination condition than for the locomotion condition, whereas the latencies for the early blind group in both conditions were similar to those of the other groups in the imagination condition.

Rieser *et al*. (1982) suggested that this pattern of results reflected differences in the way the task was performed. In the locomotion condition, the previous visual experience of the sighted and adventitiously blind groups afforded them a sensitivity to the changing perspective structure of the environment and thus allowed them to update their position automatically as they moved (cf. Gibson, 1986). In the imagination condition, without the locomotor information to support automatic updating, these groups had to resort to a strategy of calculating the relative positions of the landmarks. The early blind group, with similarly long latencies and high errors for the locomotion and the imagination conditions, appear to have used a calculation strategy in both conditions.

However, not all studies found poorer performance in early and congenitally blind participants. Loomis *et al*., (1993), in a replication of the Rieser *et al*. (1982; 1986) study, found no significant group differences in error scores and all but one of the early blind participants performed at the level of the sighted participants. However response latencies of the early blind participants were higher than those of the sighted participants, which might suggest a speed/accuracy trade-off consistent with the use of a calculation strategy by the visually impaired participants. Moreover, Loomis *et al*. acknowledge that their participants had more experience of independent mobility that those of Rieser *et al*. (1982; 1986). Similarly, Klatzky *et al*., (1995) found no differences between congenitally blind, late blind and sighted groups on a range of spatial tasks including those involving mental rotation and inference.

Hill *et al*., (1993) and Gaunet and Thinus-Blanc (1997) looked at the exploration strategies used by blind participants as they learned a large-scale layout of four objects in a large room similar to that of Rieser *et al*. (1982;1986 see Figure 2). From observation of the participant's behaviour, each of these studies identified a number of strategies used to learn the experimental layouts; these are listed in Table 1. All studies found a significant relationship between the pattern of strategy use and performance on tests of spatial knowledge of the experimental layout. Specifically, Hill *et al*. found that perimeter and gridline strategies used in isolation gave good knowledge of object location (indicating knowledge of the individual locations of objects), however in a test of integrated ('map-like') spatial knowledge of the layout, participants who used the perimeter strategy tended to perform poorly. Good performers tended to use object to object, perimeter to object or home-base to object strategies, and also used a wider range of strategies.

Table 1: Strategies identified in the studies by Hill, *et al*. (1993) and Gaunet and Thinus-Blanc (1996)

Strategy	**Description**	**Studies**
Perimeter	Explored the boundaries of an area to identify the area's shape, size and key features around its perimeter, by walking along the edge of the layout	Hill *et al*.
Grid	Investigated the internal elements of an area to learn their spatial relationships, by taking straight-line paths from one side of the layout to the other.	Hill *et al*.
Object to object	Moving repeatedly from one object to another, or feeling the relationship between objects using hand or cane.	Hill *et al*.
Perimeter to object	Moving repeatedly between an object and the perimeter	Hill *et al*.
Home base to object	Moving repeatedly between the home base (origin point for exploration) and all the others in turn	Hill *et al*.
Cyclic	Each of the four objects visited in turn, and then returning to the first object	Gaunet and Thinus-Blanc
Back-and-forth	Moving repeatedly between two objects	Gaunet and Thinus-Blanc

Gaunet and Thinus-Blanc found that the cyclic patterns were used predominantly by early blind participants, whereas late blind and blindfolded sighted participants tended to use the back-and-forth strategy. Both within and across groups, use of a back-and-forth strategy was associated with good performance, whereas cyclic exploration was associated with poor performance, on a number of tests of spatial knowledge of the layout. The authors suggest that cyclic exploration formed the basis of a sequential representation of the layout whereas the back-and-forth strategy, like the object to object strategy of Hill *et al*., formed the basis of a more integrated representation.

Novel Environments
Although constructed environments allow us to test spatial performance independently of prior learning, practical considerations restrict these environments to a relatively small scale, typically within a large room. Exploration of such environments does involve locomotion, but the distances involved are very limited, and importantly are less than the normal range of humans. By testing participants in real environments with which they are unfamiliar, we gain the advantages of both familiar spaces (ecological validity) and of novel spaces control of experience. The cost is in terms of the practicality of familiarising large numbers of participants with a large chunk of urban environment, and consequently relatively few studies of this kind have been carried out.

Dodds *et al*. (1982) introduced congenitally and late totally blind children (mean age: 11.5 years) to a short urban route by leading them along it four times. As they walked the route children were repeatedly asked to make pointer estimates to a number of locations along the route. Overall, errors in direction estimation increased with distance from the target, but this effect was considerably greater for the congenitally blind children, who were less accurate overall than the late blind children. This finding suggests that visual experience facilitated the construction of co-ordinated spatial representations of locomotor displacements. As all the children were able to walk the route, Dodds *et al*. argued that the congenitally blind children must have coded the route in terms of body centred distances and changes of heading, but were not able to integrate this information into an externally based representation of the layout. However, it is clear that this is not a necessary consequence of a lack of visual experience, as a number of congenitally blind participants performed at a similar level to sighted participants. Similar results were found by Espinosa *et al*. (1998) with blind adults in an unfamiliar parts of central Madrid and suburban Sheffield.

In another study, Ochaíta and Huertas (1993; Ochaíta *et al*., 1991; Rosa and Ochaíta 1993) familiarised blind children and adolescents (from 9 years to 17 years) with a route linking seven landmarks in a real environment (school grounds or a public square) by leading them along it once. On three subsequent days, each participant led the experimenter along the route. At the end of each session, participants were asked to construct a scale model of the space and to estimate between-landmark distances. No differences were found between congenitally blind and late blind groups on either measure.

Passini and Proulx (1988) asked blind and sighted adults to walk a route through two floors of a large, unfamiliar office building. After two guided walks, the participants were asked to walk the route unguided, while thinking aloud about the wayfinding decisions they made. The participants were then asked to produce a model of the route. The blind participants made significantly more wayfinding decisions and used more units of information (e.g., landmarks) than did the sighted group. However, both groups were equally able to produce models of the route.

Summary
With studies of large-scale space, the results have been less consistent. Most studies agree that early-blind participants perform as well as late-blind and sighted participants on tasks that involve spatial memory (e.g., reproducing angles or distances). However in tasks involving spatial inference (e.g., short-cutting, inferring crow's-flight directions) the results are inconsistent: early-blind participants generally perform more poorly, but often no differences are found. Importantly, many studies have reported that some congenitally or early blind individuals perform well within the range of sighted or late-blind groups. These individual differences indicate that the poor mean performance of blind groups does not reflect a necessary impairment in spatial ability resulting from lack of visual experience. Other kinds of experience and/or strategies used to solve the tasks are more likely to account for these individual differences.

Explaining the Data

What, then, do these studies tell us about the spatial cognition of blind and visually impaired people? As we have already pointed out in the first section of this chapter, a strong 'deficiency' theory (e.g., von Senden 1938) will not do. In many of the studies cited above, congenitally, totally blind participants were found to perform at the level of sighted participants on spatial tasks, including tests of spatial inference. We can confidently say that lack of visual experience does not prevent the acquisition of spatial representation.

As regards 'inefficiency' and 'difference' theories, it is less clear from the data which of these better characterises the spatial cognition of blind people. This is partly because the studies themselves were often not designed to make this distinction. Poorer performance by congenitally blind groups versus later blinded and sighted groups could be due to spatial processing and/or storage which is necessarily inferior in the absence of visual experience, or to the habitual use of different information processing strategies which produce poorer performance.

Two recent publications have argued convincingly for an interpretation in terms of difference. Both consider the poorer performance of congenitally blind groups on certain spatial tasks to be due to the use of different strategies: Millar (1994) emphasises coding strategies while Thinus-Blanc and Gaunet (1997) focus on behavioural strategies.

Millar: Informational Conditions and Spatial Coding

In her recent book, Millar (1994; see also 1995 and 1997 for excellent summaries of her approach) proposes a new theory of spatial representation based on research with blind and sighted people. According to her approach, the study of spatial understanding and representation in the absence of visual experience tells us a great deal about spatial cognition in general, as well as providing practical solutions to the needs of blind adults and children. Central to her theory is her 'working model' of spatial development, called 'CAPIN' (convergent active processing in interrelated networks). According to this, information from each of the different senses is specialised but also complementary and overlapping, providing a significant degree of redundancy in the information entering the system.

Because of this overlap, spatial information is not the exclusive domain of one sensory modality. Spatially relevant information is available through senses other than vision (e.g., through hearing, touch and movement) and this information can form the basis for spatial coding. However, the lack of one sense within the system tends to bias the way in which information is coded. While vision provides ready access to reliable information about external frames of reference (i.e. the relationship between external surfaces), touch, hearing and movement do not. The most reliable forms of coding in these conditions are those based on the body and on movement of the limbs. For this reason, congenitally blind children and adults generally tend to use egocentric coding in spatial tasks. While such coding strategies are most reliable for many spatial tasks, there are some tasks, e.g., those involving mental rotation or spatial inference, for which coding relative to external frameworks is advantageous.

The important point is that the processing of spatial information by congenitally blind people is not *necessarily* less efficient than in sighted people, as the 'inefficiency' theory proposes. It is misleading to focus purely on levels of efficiency rather than on the nature of coding used by participants. Congenitally totally blind people tend to code spatial relations egocentrically because this type of strategy generally works best for them. Moreover it is not the case, as Piaget and his colleagues (Piaget *et al*., 1960) argued, that egocentric coding is simply an immature stage of development which is later entirely superseded by more logically rigorous forms of coding (e.g., Euclidean geometry). Millar points out that even very young children can use external frames of reference in certain task conditions, and that sighted adults often use egocentric frames of reference in situations where these are most reliable and efficient.

In large-scale space, Millar argues, this tendency to code spatial relations egocentrically results in a tendency to form sequential representations based on routes in contrast to the more global, map-like, externally-based representations characteristic of sighted people. However, it is stressed that the former means of coding is not necessarily inferior to the latter; it is simply more reliable under blind conditions in most cases. Millar points out that it is even possible to form map-like representations on the basis of route coding, although more cognitive effort is required to reach this level.

The information provided by the intact senses is potentially adequate to support other types of spatial coding (e.g., externally based representations), provided blind children are systematically provided with the right kinds of cues for coding information by external frameworks. The practical task ahead, as Millar sees it, is to identify a range of methods for providing these cues. Possible interventions consistent with Millar's analysis are discussed in the next section.

Thinus-Blanc and Gaunet: Behavioural Strategies and Performance

In their recent paper, Thinus-Blanc and Gaunet (1997) review a number of studies on the spatial performance of early- and late-blinded people, including studies on small-scale and large-scale environments. They point out that the main difference between early blind people on the one hand and sighted and late blinded people on the other is in tests of spatial inference in locomotor space. In tasks where participants are asked to infer angles, distances or paths on the basis of a limited amount of spatial information, performance is generally better by late-blinded and sighted participants. However there are a number of revealing discrepancies in the data, which appear to be based on subtle variations in experimental factors and/or differences in the characteristics of participants.

The approach to explaining these discrepancies suggested by Thinus-Blanc and Gaunet, is to examine the ways in which people get to know their environment and solve spatial problems: in other words, the behavioural strategies spontaneously used by participants in spatial tasks. They define *strategy* as: 'a set of functional rules implemented by the participant at the various phases of information processing... [which] is assumed applicable to a wide range of situations' and allows the participant to 'reach an acceptable performance level without excessive cognitive effort' (p.36). Although this differs from Millar's (e.g., 1994) use of the term (to mean a form of coding), these functional, behavioural strategies may well be associated with particular coding strategies, for instance a combination of a perimeter strategy, a perimeter to object strategy and an object to object strategy in the study by Hill *et al*. (1993) may be the behavioural counterpart of an external 'mapping' coding strategy, in which all objects are related to each other and to the outer frame of the room.

Thinus-Blanc and Gaunet propose three steps for such a research project. Firstly, we must identify whether any behavioural regularities (e.g., different exploratory behaviours) can be consistently observed in both blind and sighted participants. Secondly, we need to identify which of these behaviours correlate with performance on various spatial tasks and thus merit the name 'strategy'. Finally a fine analysis of the strategies must be carried out to identify the actual cognitive mechanisms underlying them. This approach can potentially inform theory and generate a set of 'optimal' strategies which could form the basis of future training programmes for the poor performing blind participants.

This kind of approach has already been used to investigate the performance of blind and visually impaired people in small-scale (Gaunet *et al*., 1997; Ungar *et al*., 1995b; 1997a) and large-scale (Gaunet and Thinus-Blanc, 1997; Hill *et al*., 1993; Tellevik, 1992) spatial tasks, and in tasks requiring transfer from small-scale to large-scale (Ungar *et al*., 1996a).

Summary

In both the preceding explanations, differences in spatial performance by blind participants correspond to differences in behavioural and/or coding strategies used to acquire and organise spatial information. The fact that lack of visual experience tends to lead people to use particular strategies, accounts for the group differences observed in tests of spatial inference in locomotor space. It is a group *tendency* rather than an i*nability* that gives rise to apparent differences at the group level.

MAXIMISING SPATIAL POTENTIAL

Education

Several practical implications for educators spring from Millar's (1994) analysis. The information about the structure of external space, which is so accessible in vision, must be substituted via touch and or hearing. How this is to be done effectively is not straightforward. Millar stresses the importance of building on the information and coding strategies currently available to a blind child, and progressively integrating new sources of reference information with these existing ones; simply exposing a child to a new source of information which is rich in external cues (e.g., an electronic device, or an acoustically rich room) may not automatically cause the child to adopt a new coding system (Millar, 1994; 1995).

Similarly, training blind children or adults to use more effective behavioural strategies, as suggested by Thinus-Blanc and Gaunet (1997), may not automatically bring about changes in coding. For example, Ungar *et al*., (1995a) trained young blind and visually impaired children in strategies for learning a complex tactile map, based on the most effective strategies observed in a previous study (Ungar *et al*., 1997a). After training, there was no change in participants' performance; the poorer participants appeared not to be able to apply the trained strategies and retained their habitual coding strategies. Such training perhaps needs to be more closely integrated with children's existing strategies and their understanding of space.

Methods for encouraging young blind children to explore independently may well facilitate their understanding of the structure of external space. Because a blind child is unable to detect environmental dangers like steps (even a small one is enough to cause a fall) and jagged edges, she may become reluctant to move out into space. Simply providing the child with a probe in the form of a cane or a wheeled toy may reduce this emotional barrier to movement (Morsley *et al*., 1991; Pogrund *et al*., 1993; Pogrund and Rosen, 1989).

Vision Substitutes

Another approach has been to substitute vision with an electronic device that converts optical information about objects in the environment into auditory or tactile information. One such device, the Sonicguide™ (Kay, 1974) has been used in several studies with visually impaired infants and young children. It was hypothesised that providing children with auditory information about objects and surfaces in external space from an early age would facilitate their general understanding of the environment. In one study by Aitken and Bower (1982a; 1982b) three congenitally blind infants were given frequent sessions wearing the Sonicguide™ by their parents. The youngest of the three infants showed a number of spatially oriented behaviours (such as reaching and grasping) at approximately the appropriate age for sighted children whereas the other two infants apparently did not benefit from the Sonicguide™ at all. Warren (1994) provides a critical commentary on these and other, similarly inconclusive, studies.

In a new approach to sensory substitution, the Neural Rehabilitation Engineering Laboratory of the University of Louvain are integrating research in neuroscience, psychology and other fields to produce 'a model of the deprived sensory system connected to an inverse model of the substitutive sensory system' (PSVA, 1997). With recent advances in technology in the neurosciences, such a goal is increasingly realisable, and meshes well with Millar's (1994) recommendation to reintroduce the required redundancy into the system as a whole.

Tactile maps

Another potential tool for introducing blind and visually impaired people to the layout of the environment is a tactile map. A tactile map can provide a vicarious source of spatial information that preserves all the interrelationships between objects in space but presents those relationships within one or two hand-spans. The relevant information is presented clearly (irrelevant 'noise' which may be experienced in the actual environment, is excluded); with relative simultaneity (a map can be explored rapidly with two hands and with less demand on memory); and without other difficulties associated with travel in the real environment (e.g., veering or anxiety). Furthermore, if maps can encourage blind people to represent the environment by externally based codes, they may form a crucial component of mobility training (Gilson *et al.*, 1965; Yngström, 1988).

It should be noted that tactile maps might have at least two important benefits. In a short-term sense, they can be employed to introduce a blind person to a particular space. However, the exercise of relating a map to the environment it represents, can potentially improve abstract level spatial thought in the long term, for instance encouraging the use of externally based coding frameworks for structuring spatial representations of the environment by making the spatial relations between locations more accessible (Millar, 1994; 1995).

Espinosa *et al*. (1998) asked blind adults to learn a route through a novel environment either using a tactile map or by direct experience. Their knowledge of the route was tested by asking them to walk the route unguided (route knowledge) and to make direction estimates between locations on the route (inferred knowledge of the layout of the environment). Performance on both measures was best when participants learned the route by a combination of tactile map and direct experience. Participants who learned the route by direct experience alone performed poorly on both measures. Similar results were found in studies by Bentzen (1972) and by Brambring and Weber (1981), indicating that tactile maps can provide congenitally and early blind people with a cleared impression of the spatial layout of an environment.

The evidence from the few studies with visually impaired children suggests that they have the potential to learn about, understand and use simple maps to perform orientation tasks in the environment [2]. However, until recently the evidence about visually impaired children's map use was based on small groups of older children (e.g., Gladstone, 1991) or single case studies (e.g., Landau, 1986). Therefore we carried out a number of experiments considering the potential of visually impaired children from five to twelve years to understand and use maps (Ungar *et al.*, 1996a; 1997a; 1997b; Ungar *et al.*, 1994)

In one study, we compared the performance of visually impaired children (aged from 5 to 11 years) who were asked to learn about an environment *either* by directly exploring that environment *or* by being shown a tactile map of it (Ungar *et al.*, 1994). The environment consisted of a number of familiar toys arranged randomly around the floor of a large hall (see Figure 3). Tactile maps were constructed showing the location of all the toys. Both the totally blind and the partially sighted children were able to understand and use the maps. Most importantly, we found that the totally blind children learnt the environment more accurately from the map than from direct exploration. The results of this study demonstrated the importance of tactile maps for helping young totally blind children to form an impression of the space around them.

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[2] It has been suggested that young children cannot use maps, as they lack an understanding of symbolic systems, specifically they lack an understanding that a map 'stands for' or represents the environment (e.g. Liben and Downs, 1989; Millar, 1994). However, research has shown that even pre-school sighted children can understand and use simple maps for simple tasks (Blades, 1994). These children can make use of the 'correspondences' between the map and the environment (e.g. to make appropriate spatial responses) even if they do not yet fully understand how the map functions as a representation of the environment.

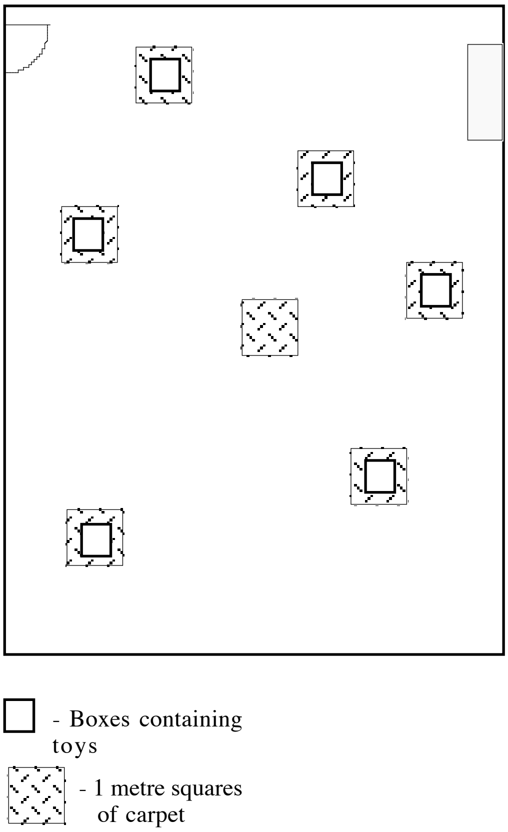

Figure 3: Example of the layout used by Ungar et al. (1994).

The general finding from our work is that young visually impaired children do have the potential to understand and use tactile maps. In some studies (e.g., Ungar *et al*., 1996a; Ungar *et al*., 1997a) it was found that the strategies children used to perform the map tasks affected their performance; visually impaired children who adopted effective tactile strategies often performed as well as or better than sighted and partially sighted children.

Summary
These studies indicate that even young blind children can acquire knowledge about the spatial structure of an environment from a tactile map, and use this knowledge to make spatial decisions. Thus, tactile maps might be an ideal means for emphasising external frameworks in the environment, which are not readily apprehended by direct experience alone. Spatial knowledge may be optimised when tactile maps are used in conjunction with direct experience of the environment, supporting Millar's (1994; 1995) recommendation that new strategies should be integrated with existing ones. Individual differences in tactile mapping use may be accounted for by differences in strategies used to acquire information from the maps, and it may be possible to train poorer map readers in more effective strategies.

Despite the optimistic findings of this research, tactile maps are still little used in practice, both in the classroom and in the outside world. Educators do not always have the time or resources to keep abreast of the latest developments in research. Furthermore, there is very little in the way of standards for the design and construction of tactile maps; practitioners make use of the resources they have to hand, and as a consequence, may find themselves reinventing the wheel. Closer links are clearly needed between the research and practitioner communities.

Environmental Modification and Universal Design

Recent developments in the sociology of disability and the rise of disabled peoples' movements have forced people researching impairment to reflect on the role of their work in relation to the lives of disabled people (Imrie, 1996; Kitchin, 1998; Oliver, 1990). In particular, a 'social model' of disability has been formulated which challenges the traditional, essentialist view of disability as a direct consequence of impairment. According to the social model, disability arises when environmental barriers (social, political or physical) prevent a person with impairments from functioning in society in the same way as able-bodied people. Focusing exclusively on the impairment can lead to solutions that attempt to fit the person to their environment, ignoring possibilities for adapting the environment to the person. The social model requires that disability be considered from the broadest possible perspective, where environmental modifications are preferred but intervention at the level of the individual is not ruled out.

Related to this, the principle of ‘universal design’ suggests that sensitive planning and design can yield environments that are equally suited to all people. This points us to environmental modifications which may benefit large numbers of people. Talking signs are an example of an environmental orientation aid which may be useful for blind and sighted people alike (Ungar, in preparation).

THE FUTURE

In this final section, I will attempt to do two things: to hazard one or two guesses as to some likely directions of research in this area; and to highlight some areas which I think deserve attention in the future. This crystal ball gazing is necessarily based on my own personal experience and perspective within the field.

Early Experiences: Structuring the Young Child's Spatial Experiences

One implication of the research on coding strategies (Millar, 1994) and behavioural strategies (Thinus-Blanc and Gaunet, 1997; Ungar, 1996) is that early experience influences the way blind children process spatial information. Even at the earliest school age, children with similar levels of visual impairment already differ in their performance on spatial tasks. This leads to an emphasis on how the early environment and activities of blind infants are structured: in the absence of the structuring effect of vision, how do infants learn about the space around them?

Few studies have looked specifically at sources of spatial information in the environments of blind infants. In a review of the sparse literature, Warren (1994) identifies aspects of both the physical and social environment that may influence subsequent cognitive development. In this sense both the opportunity to explore the properties and layout of the physical environment safely, and the encouragement to do so may both be important.

Nielsen (1991) developed a 'little room' in which blind infants could explore a range of objects without the distracting and unpredictable noises of larger environments. She found that infants who were systematically exposed to this restricted environment exhibited relatively precocious search behaviour.

A number of studies on the social development of blind children (Als *et al*., 1980; Pérez *et al*., 1994; Preisler, 1991; Rattray and Zeedyk, 1995; Rowland, 1983; Urwin, 1978) suggest that the joint activities of infant and caregiver are very different when the infant is blind. Caregivers often do not naturally compensate for their infant's impairment, and must learn to read the different kinds of social cues that the infant gives and respond to these. Likewise, it is possible that caregivers do not structure their interactions with their infant in a way that would optimise her experience of space. This aspect of early development has not received sufficient attention.

The 'Neglected' Visually Impaired

While the literature on the effects of total blindness increases rapidly, there has been little research into the effects of differing degrees and types of visual impairment on spatial cognition. This is partly due to the historical significance of the Molyneux question (discussed earlier) which gives a more general theoretical importance to the study of blindness and space, but also to the increased complexity of designing studies which control for the varying profile of visual impairment across the population.

In one study that attempted to address these broader questions, Rieser *et al*. (1992) asked blind adults with varying degrees and types of residual vision to make direction and distance estimates in a familiar area. For the participants with early onset of impairment, they found that degree of field loss, but not degree of acuity loss, was negatively associated with accuracy of estimates. This result qualifies the finding (e.g., Rieser *et al*., 1982; 1986) that lack of visual experience *per se* leads to difficulties in acquiring integrated representations of locomotor space. Here some forms of visual impairment led to difficulties while others did not. This result has major implications for provision of education and services for people with visual impairments and deserves to be the focus of research in the future.

Neuropsychology

With recent advances in techniques for scanning brain activity, a number of studies has considered the possibility that differences in processing spatial information between blind and sighted people may be evident at the level of brain function. In other words, lack of early visual experience may lead to different parts of the brain being used for spatial tasks. Studies using positron emission tomography (PET scan) (Veraart *et al*., 1990; Wanet-Defalque *et al*., 1988) and electroencephalogram (EEG) (Röder *et al*., 1997), for instance, have found that activity in the occipital area of the cortex, usually used for processing visual signals, is generally higher than in sighted and late-blind people. This generalised increased activity is unlikely to support any specific brain function and is probably the result of surviving synaptic connections which normally disappear as a result of visual experience (Thinus-Blanc and Gaunet, 1997).

Another study using PET (Catalan-Ahumada *et al*., 1993) found similarly raised levels of occipital activity during a spatial localisation task, but also detected lower activity in the Parietal Area 7 of early blind participants. As Parietal Area 7 has been associated with spatial processing, the authors speculated that the difficulties with spatial tasks may be based in reduced function in this area.

Further developments in this field may well reveal further differences in localised brain function between early blind and sighted or late blind people. As our understanding of brain function increases, this may lead to new ways of substituting sensory information for early blind people. For instance, the Neural Rehabilitation Engineering Laboratory of the University of Louvain is simultaneously investigating differences in brain function and developing methods of sensory substitution based on this research.

Cognitive Maps and Urban Design

To some extent turning cognitive mapping research on its head, Vujakovic and Matthews (Matthews and Vujakovic, 1995; Vujakovic and Matthews, 1994) examined the extent to which differences in cognitive maps of special populations (in their case wheelchair users) reflect their experiences of the built environment. In their study, Vujakovic and Matthews asked geography undergraduates and wheel-chair users working together in pairs to produce maps of the city centre of Coventry which reflected the wheel-chair users' experiences of mobility in that area. In particular, one map showed the causes of specific mobility blackspots while another revealed the uneven 'mobility surface' of the area, where streets were graded according to their level of accessibility. Through the process of externalizing their cognitive maps of the area, the wheel-chair users could contribute to the mapping process and at the same time make a political statement about the level of service provision to disabled people in Coventry.

The emphasis here is on the structure of the built environment itself rather than on the representation or processing of this structure. Rather than treating the cognitive maps of their participants as distortions of reality (Golledge, 1993), the maps were considered to be versions of reality reflecting a pressing need for environmental modification. The cognitive maps thus take on a political significance over and above their psychological interest. This method could usefully be applied to blind and visually impaired people (as indeed to many other minority populations). The added spatial aspect of this research can enrich previous questionnaire based studies of environmental barriers for blind and visually impaired people (Passini *et al*., 1985; Passini *et al*., 1986).

GIS and GPS

Another technological development may reduce or obviate the need for cognitive maps. The combination of geographical information systems (GIS) and global positioning systems (GPS) allows us to pinpoint our location quite precisely, and can give us detailed instructions about how to get to our destination. Such systems are already in use for in-car navigation and are being developed for use by blind people (Golledge *et al*., 1991; Jacobson, 1994). Golledge and his colleagues (Golledge *et al*., 1991; Golledge *et al*., 1998) have been developing a portable personal guidance system which can provide a blind traveller with constantly updated information about their position and heading, about local objects, and can provide information about optimal routes. A major advantage of this technology is that the GIS component can be updated regularly providing the user with up-to-the-minute information about the accessibility of different routed within the environment. It seems likely that the ever-reducing cost and size of such technology will bring it within the reach of most blind people in the not-too-distant future. The effect this will have on their spatial understanding will be another interesting research question for the future.

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REFERENCES

Aitken, S. and Bower, T.G.R. (1982a) Intersensory substitution in the blind. *Journal of Experimental Child Psychology,* 33, 309-323.

Aitken, S. and Bower, T.G.R. (1982b) The use of the Sonicguide in infancy. *Journal of Visual Impairment and Blindness,* 76, 91-100.

Als, H., Tronick, E. and Brazelton, T.B. (1980) Stages of early behavioural organization: The study of a sighted infant and a blind infant in interaction with their mothers. In Field, T.M., Ed., *High-Risk Infants and Children, Adult and Peer Interactions* . New York: Academic Press.

Andrews, S.K. (1983) *Spatial cognition through tactual maps.* Paper presented at the 1st Int. Symposium on Maps and Graphics for the Visually Handicapped, Washington.

Bentzen, B.L. (1972) Production and testing of an orientation and travel map for visually handicapped persons. *New Outlook,* 66, 249-255.

Blades, M. and Spencer, C. (1994) The development of children's ability to use spatial representations. In Reese, H.W., Ed., *Advances in Child Development and Behaviour*, 25. New York: Academic Press, pp. 157-199.

Brambring, M. and Weber, C. (1981) Taktile, verbale und motorische informationen zur geographischen orientierung blinder. (Tactile, verbal and motor information on the geographic orientation of the blind). *Zeitschrift für Experimentelle und Angewandte Psychologie,* 28, 23-37.

Casey, S. (1978) Cognitive mapping by the blind. *Journal of Visual Impairment and Blindness,* 72, 297-301.

Catalan-Ahumada, M., De Volder, A.G., Melin, J., Crucq, B. and Veraart, C. (1993) Increased glucose utilization in the visual cortex of blind subjects using an ultrasonic device. *Archives Internes de Physiologie et de Biochimie,* 101, 29.

Dodds, A.G., Howarth, C.I., and Carter, D.C. (1982) The mental maps of the blind: the role of previous experience. *Journal of Visual Impairment and Blindness,* 76, 5-12.

Espinosa, M.-A., Ungar, S., Ochaíta, E., Blades, M. and Spencer, C. (1998) Comparing methods for introducing blind and visually impaired people to unfamiliar urban environments. *Journal of Environmental Psychology,* 18, 277-287.

Fletcher, J.F. (1980) Spatial representation in blind children 1: development compared to sighted children. *Journal of Visual Impairment and Blindness,* 74, 318-385.

Foulke, E. and Hatlen, P.H. (1992). A collaboration of two technologies. Part 1: Perceptual and cognitive processes: their implications for visually impaired persons. *British Journal of Visual Impairment,* 10, 43-46.

Gaunet, F., Martinez, J.-L. and Thinus-Blanc, C. (1997) Early-blind subjects' spatial representation of manipulatory space: exploratory strategies and reaction to change. *Perception,* 26, 345-366.

Gaunet, F. and Thinus-Blanc, C. (1997) Early-blind subjects' spatial abilities in the locomotor space: exploratory strategies and reaction-to-change performance. *Perception,* 25, 967-981.

Gibson, J.J. (1986) *The Ecological Approach to Visual Perception*. New Jersey: Lawrence Erlbaum Associates.

Gilson, C., Wurzburger, B. and Johnson, D.E. (1965) The use of the raised map in teaching mobility to blind children. *New Outlook,* 59, 59-62.

Gladstone, M. (1991) *Spatial Cognition and Mapping Abilities: a comparison of sighted and congenitally blind individuals.* Unpublished Honours Dissertation, University of Edinburgh.

Golledge, R.G. (1993) Geography and the disabled - a survey with special reference to vision impaired and blind populations. *Transactions of the Institute of British Geographers,* 18, 63-85.

Golledge, R.G., Klatzky, R.L. and Loomis, J.M. (1996) Cognitive mapping and wayfinding by adults without vision. In Portugali, J., Ed., *The Construction of Cognitive Maps*. Dordrecht: Kluwer Academic Publishers.

Golledge, R.G., Klatzky, R.L., Loomis, J.M., Speigle, J. and Tietz, J. (1998) A geographical information system for a GPS based personal guidance system. *International Journal of Geographical Information Science*, 12, 727-749.

Golledge, R.G., Loomis, J.M., Klatzky, R.L., Flury, A. and Yang, X.L. (1991) Designing a personal guidance system to aid navigation without sight: progress on the GIS component. *International Journal of Geographical Information Systems,* 5, 373-395.

Haber, L., Haber, R.N., Penningroth, S., Novak, K. and Radgowski, H. (1993) Comparison of 9 methods of indicating the direction to objects - data from blind adults. *Perception,* 22, 35-47.

Hill, E.W., Rieser, J.J., Hill, M.M., Hill, M., Halpin, J. and Halpin, R. (1993) How persons with visual impairments explore novel spaces - strategies of good and poor performers. *Journal of Visual Impairment and Blindness,* 87, 295-301.

Imrie, R. (1996). *Disability and the City: International Perspectives*. London: Paul Chapman Publishing.

Jacobson, R.D. (1994) GIS and the visually disabled - the spatial contribution to mobility. *Mapping Awareness,* July, 34-36.

Kay, L. (1974) A sonar aid to enhance spatial perception of the blind: engineering design and evaluation. *The Radio and Electronic Engineer,* 44, 40-62.

Kitchin, R. (1996) Methodological convergence in cognitive mapping research: investigating configurational knowledge. *Journal of Environmental Psychology,* 16, 163-185.

Kitchin, R. (1998) 'Out of place', 'knowing one's place': Towards a spatialised theory of disability and social exclusion. *Disability and Society,* 13, 343-356.

Kitchin, R.M. and Jacobson, R.D. (1997) Techniques to collect and analyze the cognitive map knowledge of persons with visual impairment or blindness: issues of validity. *Journal of Visual Impairment and Blindness,* 91, 393-400.

Klatzky, R.L., Golledge, R.G., Loomis, J.M., Cicinelli, J.G. and Pellegrino, J.W. (1995) Performance of blind and sighted persons on spatial tasks. *Journal of Visual Impairment and Blindness,* 89, 70-82.

Landau, B., Spelke, E. and Gleitman, H. (1984) Spatial knowledge in a young blind child. *Cognition,* 16, 225-260.

Leonard, J.A. and Newman, R.C. (1967) Spatial orientation in the blind. *Nature,* 215, 1413-1414.

Liben, L.S., and Downs, R.M. (1989) Understanding maps as symbols: the development of map concepts in children. In Reese, H., Ed., *Advances in Childhood Development and Behaviour*, 22. New York: Academic Press, pp. 145-201.

Loomis, J.M., Klatzky, R.L., Golledge, R.G., Cicinelli, J.G., Pellegrino, J.W. and Fry, P.A. (1993) Nonvisual navigation by blind and sighted - assessment of path integration ability. *Journal of Experimental Psychology - General,* 122, 73-91.

Matthews, M.H. and Vujakovic, P. (1995) Private worlds and public places - mapping the environmental values of wheelchair users. *Environment and Planning A,* 27, 1069-1083.

Millar, S. (1982) The problem of imagery and spatial development in the blind. In de Gelder, B., Ed., *Knowledge and Representation*. London: Routledge and Kegan Paul, pp. 111-120.

Millar, S. (1994). *Understanding and Representing Space: Theory and Evidence from Studies with Blind and Sighted children*. Oxford: Oxford University Press.

Millar, S. (1995) Understanding and representing spatial information. *British Journal of Visual Impairment*, 13, 8-11.

Millar, S. (1997) Theory, experiment and practical application in research on visual impairment. *European Journal of Psychology of Education,* 12, 415-430.

Morsley, K. (1989) Enhancing the orientation and mobility of the visually impaired child: an evaluation of current theories and practices. Unpublished PhD thesis, Sheffield University.

Morsley, K., Spencer, C. and Baybutt, K. (1991) Two techniques for encouraging movement and exploration in the visually impaired child. *British Journal of Visual Impairment*, 9, 75-78.

PSVA - Prosthesis for Substitution of Vision by Audition, [online]. (1997) Neural Rehabilitation Engineering Laboratory of the Catholic University of Louvain. Available: http://www.md.ucl.ac.be/entites/fsio/gren/Projets/PSVA.html [21st January 1999]

Nielsen, L. (1991) Spatial relations in congenitally blind infants: a study. *Journal of Visual Impairment and Blindness*, 85, 11-16.

Ochaíta, E. and Huertas, J.A. (1993) Spatial representation by persons who are blind: a study of the effects of learning and development. *Journal of Visual Impairment and Blindness*, 87, 37-41.

Ochaíta, E., Huertas, J. A., and Espinosa, A. (1991). Representación espacial en los niños coegos: una investigación sobre las principales variables que la determinan y los procedimientos de objetivación más adecuados. [Spatial representation in blind children: an investigation into the main determining factors and the most appropriate externalization techniques]. *Infancia y Aprendizaje,* 54, 53-79.

Oliver, M. (1990) *The Politics of Disablement*. Basingstoke: Macmillan.

Passini, R., Delisle, J., Langlois, C., and Proulx, G. (1985) *Etude Descriptive de la Mobilite et de l'Orientation Spatiales chez des Handicapes Visuels en Milieu Urbain* (A descriptive study of the mobility and spatial orientation of the visually handicapped in the urban environment): Université de Montreal, Faculté de l 'Amenagement.

Passini, R., Dupré, A. and Langois, C. (1986) Spatial mobility of the visually handicapped active person: a descriptive study. *Journal of Visual Impairment and Blindness*, 80, 904-907.

Passini, R. and Proulx, G. (1988) Wayfinding without vision: an experiment with congenitally, totally blind people. *Environment and Behaviour*, 20, 227-252.

Pérez Pereira, M. and Castro, J. (1994) *El Desarollo Psicológico de los Niños Ciegos en la Primera Infancia*. Madrid: Paidós.

Piaget, J., Inhelder, B. and Szeminska, A. (1960) *The Child's Conception of Geometry*. London: Routledge and Kegan Paul.

Pogrund, R.L., Fazzi, D.L., and Schreier, E.M. (1993). Development of a preschool 'Kiddy Cane'. *Journal of Visual Impairment and Blindness*, 87, 52-54.

Pogrund, R.L., and Rosen, S.J. (1989) The preschool blind child can be a cane user. *Journal of Visual Impairment and Blindness*, 83, 431-439.

Preisler, G. M. (1991). Early patterns of interaction between blind infants and their sighted mothers. *Child: Care, Health and Development*, 17, 65-90.

Rattray, J. and Zeedyk, M.S. (1995) Early interaction of visually impaired infants and their mothers. Paper presented at the British Psychological Society Developmental Psychology Section Annual Conference, University of Strathclyde.

Rowland, C. M. (1983) Patterns of interaction between three blind infants and their mothers. In Mills, A.E., Ed., *Language Acquisition in the Blind Child: Normal and Deficient*. London: Croom Helm.

Rieser, J.J., Guth, D.A. and Hill, E.W. (1982) Mental processes mediating independent travel: implications for orientation and mobility. *Journal of Visual Impairment and Blindness*, 76, 213-218.

Rieser, J.J., Guth, D.A. and Hill, E.W. (1986) Sensitivity to perspective structure while walking without vision. *Perception,* 15, 173-188.

Rieser, J.J., Lockman, J.J. and Pick, H.L. (1980) The role of visual experience in knowledge of spatial layout. *Perception and Psychophysics,* 28, 185-190.

Rieser, J.J., Talor, C.R., Rosen, S., Hill, E.W., and Bradfield, A. (1992) Visual experience, visual field size, and the development of nonvisual sensitivity to the spatial structure of outdoor neighborhoods explored by walking. *Journal of Experimental Psychology - General,* 121, 210-221.

Röder, B., Rösler, F., and Henninghausen, E. (1997) Different cortical activation patterns in blind and sighted humans during encoding and transformation of haptic images. *Psychophysiology,* 34, 292-307.

Rosa, A., and Ochaíta, E., Eds. (1993) *Psicología de la Ceguera*. Madrid: Alianza Psicología.

Tellevik, J.M. (1992) Influence of spatial exploration patterns on cognitive mapping by blindfolded sighted persons. *Journal of Visual Impairment and Blindness,* 86, 221-224.

Thinus-Blanc, C. and Gaunet, F. (1997) Representation of space in blind persons: vision as a spatial sense? *Psychological Bulletin,* 121, 20-42.

Ungar, S. (in preparation). A city for different people: from exclusion to universal design.

Ungar, S., Blades, M. and Spencer, C. (1995a) *The effectiveness of training visually impaired children in strategies for exploring tactile maps.* Paper presented at the British Psychological Society Developmental Psychology Section Annual Conference, University of Strathclyde.

Ungar, S., Blades, M. and Spencer, C. (1995b) Mental rotation of a tactile layout by young visually impaired children. *Perception,* 24, 891-900.

Ungar, S., Blades, M. and Spencer, C. (1996a) The ability of visually impaired children to locate themselves on a tactile map. *Journal of Visual Impairment and Blindness,* 90, 526-535.

Ungar, S., Blades, M. and Spencer, C. (1996b) The construction of cognitive maps by children with visual impairments. In Portugali, J., Ed., *The Construction of Cognitive Maps*. Dordrecht: Kluwer Academic Publishers, pp. 247-273.

Ungar, S., Blades, M. and Spencer, C. (1997a) Strategies for knowledge acquisition from cartographic maps by blind and visually impaired adults. *The Cartographic Journal,* 34, 93-110.

Ungar, S., Blades, M. and Spencer, C. (1997b) Teaching visually impaired children to make distance judgements from a tactile map. *Journal of Visual Impairment and Blindness,* 91, 163-174.

Ungar, S., Blades, M., Spencer, C. and Morsley, K. (1994) Can visually impaired children use tactile maps to estimate directions? *Journal of Visual Impairment and Blindness,* 88, 221-233.

Urwin, C. (1978) The development of communication between blind infants and their mothers. In Lock, A., Ed., *Action, Gesture and Symbol: The Emergence of Language*. New York: Academic Press.

Veraart, C., Volder, A.G.D., Bol, A., Michel, C., and Goffinet, A.M. (1990) Glucose utilization in human visual cortex is abnormally elevated in blindness of early onset but decreased in blindness of late onset. *Brain Research,* 510, 115-121.

von Senden, S. M. (1932) *Space and Sight: the Perception of Space and Shape in the Congenitally Blind Before and After Operation*. Glencoe, IL: Free Press.

Vujakovic, P. and Matthews, M.H. (1994) Contorted, folded, torn: environmental values, cartographic representation and the politics of disability. *Disability and Society,* 9, 359-374.

Wanet-Defalque, M.-C., Veraart, C., Volder, A.D., Metz, R., Michel, C., Dooms, G., and Goffinet, A. (1988) High metabolic activity in the visual cortex of early blind human subjects. *Brain Research,* 446, 369-373.

Warren, D.H. (1994) *Blindness and Children: An Individual Differences Approach*. Cambridge: Cambridge University Press.

Yngström, A. (1988) The tactile map: the surrounding world in miniature. Paper presented at the 2nd International Symposium on Maps and Graphics for Visually Handicapped People, Nottingham: University of Nottingham.