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THE CONSTRUCTION OF COGNITIVE MAPS BY CHILDREN WITH VISUAL IMPAIRMENTS

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ABSTRACT

The way in which children who have visual impairments construct cognitive maps of their environment is of considerable theoretical and practical importance. It sheds light on the role of sensory experience in the development of spatial cognition which can in turn suggest how spatial skills might be nurtured in visually impaired children. In most of the studies reviewed here, groups of children who lost their sight early in life perform less well on a variety of spatial tasks than sighted children or children who lost their sight later in life. We will argue that it is not the lack of visual experience in itself which produces this pattern, but rather the effect of lack of vision on the spatial coding strategies adopted by the children. Finally we will discuss a number of methods for encouraging visually impaired children to use coding systems which are appropriate for the construction of flexible and integrated cognitive maps, with particular reference to the use of tactile maps.

INTRODUCTION

The spatial abilities of visually impaired people have been a focus of study within psychology for both theoretical and practical reasons. We can discover a great deal about the nature of spatial representation in general by studying cases of sensory deprivation — for instance, whether spatial representations are necessarily based on visually derived codes. In practical terms, a greater understanding of the way in which visually impaired people represent space is important for the development of methods for improving their spatial skills.

It is now generally believed that visually impaired people can acquire spatial concepts and representations through their intact senses, but there is still some debate about the level of representation which can be constructed on the basis of non-visual information. A number of authors suggest that visually impaired people are limited to a relatively fragmentary and inflexible representation of the environment. Others, however, believe that the representations of visually impaired people are limited only by their experience of the environment and that even totally congenitally blind people have the potential to form integrated representations of an environment if provided with sufficient appropriate experience.

This chapter focuses on the construction of spatial representations by children with visual impairments. We will consider the ways in which visually impaired children come to understand the spatial structure of their environments and their potential for acquiring more powerful representations. For convenience, the literature in this area will be considered under two general headings — small-scale space and large-scale space — although these are intimately related. We shall also report some of the work on spatial representation in visually impaired adults where this clarifies or strengthens findings from the literature on children.

THEORETICAL BACKGROUND ON SPATIAL DEVELOPMENT

Foulke (1982; Foulke and Hatlen, 1992) argued that vision is the 'spatial system par excellence', on the basis that no other sense has such scope or clarity. Fletcher (1980) has identified three broad theoretical positions which have existed in the literature on the spatial concepts of visually impaired people. The first of these, which Fletcher calls the 'Deficiency Theory', is exemplified in the work of von Senden (1932) who concluded that spatial concepts are impossible in people who have been blind from birth, and that visual experience for some part of life is essential for even a minimal understanding of space. This theory is now primarily of historical interest as more recent research has largely discredited Senden's position.

The second theoretical strain identified by Fletcher is the Inefficiency Theory which suggests that people who are blind from birth develop concepts and representations of space but that they are functionally inferior to those of the sighted and the late blind. This theory continues to receive support, especially from researchers in the Gibsonian tradition (e.g. Rieser, 1990; Rieser et al., 1986) who have found that the congenitally blind have difficulty mentally updating their position in an environment experienced through locomotor exploration. Researchers have also shown that the congenitally blind tend to construct representations of environments experienced through locomotion in terms of linear routes consisting of sequences of paths linked by decision points. Such a representation would not support the inferences about the relative locations of places that are possible with an overall, survey representation of space.

The third theoretical position is the Difference Theory which proposes that the visually impaired may build up a set of spatial relations, which are functionally equivalent to those of the sighted, but that they do so more slowly and by different means. For example, Juurmaa (1973) suggested that the visually impaired do attain a spatial competence equivalent to that of the sighted by mid-adolescence. Juurmaa proposed that this delayed development of spatial cognition in the visually impaired relative to the sighted may, in part, account for the differences found between these groups when peers are compared on spatial tasks. Juurmaa also argued that the poor performance of the visually impaired relative to blindfolded sighted participants on many tests of spatial competence is attributable to the use of experimental stimuli which are highly familiar to the sighted but less so for the visually impaired participants. For example, in a study by Worchel (1951), participants were led along two sides of a triangle and then asked to return to the start. Congenitally blind participants performed less well than blindfolded sighted participants. The sighted participants may have had a much stronger mental image of a triangle prior to the experiment than the visually impaired participants.

There are, of course, alternatives to vision. The haptic-proprioceptive system can provide precise spatial data, but only within the scope of the body itself, and therefore, as a blind person moves through the environment encountering objects, sounds, underfoot textures etc., this sequence of sensory impressions must be actively cognitively constructed to form an ordered representation. The auditory system also provides access to stimuli, and over a more extensive range, but it is much less useful for precise localisation.

Juurmaa (1973) claims that although the visually impaired lack the quantity and quality of spatial experience which is constantly available to the sighted individual, the developmental delay could nevertheless be minimised if visually impaired children are provided with enough experience of the right kind from an early age. Millar (1988) agrees that senses other than vision are less adequate for coding spatial relational information, but argues that the potential of the visually impaired to acquire a fully integrated representation of space is no less than that of the sighted.

REPRESENTATION OF SMALL-SCALE SPACES: CROSSMODAL INTERACTION

The study of the interrelationship between the sensory modalities has important implications for theories of spatial cognition of visually impaired people. Central to this issue is whether sensory information is coded in the brain in a way that is specific for each modality or whether information is re-coded in more uniform way, and independently of any specific modality (Millar, 1981; Warren, 1984). According to the former belief, environmental information would retain the features of the sensory modality through which it was apprehended and given Foulke's (1982; Foulke and Hatlen, 1992) analysis this would predict that visually impaired people, relative to people with sight, are impaired in the ability to encode spatial information.

A number of studies on cross-modal functions in visually impaired and sighted children (Hermelin and O'Connor, 1971; Hermelin and O'Connor, 1975; Hermelin and O'Connor, 1982; Millar, 1981; O'Connor and Hermelin, 1972) have shown that the modality used in tasks influences the way in which information is encoded. For instance, O'Connor & Hermelin (1972) presented congenitally totally blind and blindfolded sighted children with sequences of auditory stimuli which were separated in space. They randomly varied the relationship between the temporal and spatial sequencing of presentation of the stimuli. Both groups tended to report the 'middle' stimulus as being the temporally middle rather than the spatially middle stimulus. In contrast, sighted children performing an identical task with visual rather than auditory stimuli tended to choose the spatially middle stimulus. This result suggests a general tendency to structure information differently in the two modalities; auditory information being structured according to temporal occurrence and visual information being structured spatially.

It has also been shown that visual experience influences the coding of tactile and kinaesthetic information in non-visual tasks. Hermelin & O'Connor (1971; 1975) presented congenitally totally blind and sighted children with two tasks which examined the tendency to code spatial information according to self-referent or external cues. In both tasks it was found that most of the visually impaired children used a coding strategy with reference to their own body. Sighted children, in contrast, tended to code spatial position and movement within an external frame of reference. However, the fact that a small number of visually impaired children did use external cues suggests that visual experience is not a *necessary* requirement for the development of an exterocentric system of reference. A number of other studies which have found group differences between early blind and sighted participants on spatial tasks also report a number of early blind people who perform similarly to the sighted (Casey, 1978; Dodds et al., 1982; Fletcher, 1980).

This phenomenon is discussed by Millar (1975; 1976; 1979; 1981; 1988) in her extensive analysis of the representation of tactile and kinaesthetic spatial information by visually impaired children. Millar (1988) argued that spatial information can be derived from hearing, touch and movement and that the visually impaired therefore have the *potential* to acquire concepts and representations of the spatial domain equivalent to those of the sighted. Millar (1988) emphasized the importance of recognizing the basic potential of children to acquire certain skills before interpreting the performance of children in tests of those skills.

Millar (1988) proposed a model of sensory deprivation in which the 'type and reliability of spatial information' (p. 72) available to visually impaired children differs from that available through vision and these differences in the quality of experience can prompt the child to organize spatial information by different coding strategies from those which arise from visual experience. In this respect, it is important to reassess the concept of 'ability' as being a level of competence in a certain, spatial or other, skill. The lack of vision and the resulting difference in the quality of experience of space lead the child to approach a task in a different way, using different strategies. The tendency for congenitally blind children is to use self-referent and movement coding strategies because, in the absence of vision, these are generally highly efficient for spatial tasks. 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 in a constant position. With vision it may be more natural to encode 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 coordinates or according to a particular, reliably reproducible arm movement. 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 identical. 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.

Studies on mental imagery in sighted people have suggested that representations of perceptible objects and events are picture-like or are at least in some way analogous to visual perception. Producing mental images of words facilitates their recall, and images can be mentally scanned and rotated just as such events would occur in perception (e.g. Kosslyn et al., 1978; Neisser and Kerr, 1973; Paivio, 1986; Shepard and Metzler, 1971). However, as Paivio (1986) points out, imagery can be derived from all the sensory modalities and therefore even congenitally blind people could, in principle, form mental images of objects based on their intact sensory modalities (especially audition and touch). In fact all of the studies cited above have been adapted for congenitally blind people to determine whether vision is necessary for mental imagery (Carpenter and Eisenberg, 1978; Kerr, 1983; Marmor and Zaback, 1976; Zimler and Keenan, 1983). In general, visually impaired participants in these studies perform very similarly to sighted participants, with the exception that reaction times tend to be rather slower for congenitally blind participants. This suggests that visual experience is not necessary for mental imagery (i.e. the representation of the spatial structure of objects and events) but that visual experience might facilitate the manipulation of images.

The findings from mental imagery tasks provide further support for the argument that visually impaired children can acquire spatial representations which are functionally equivalent to those of sighted people. Millar (1982) has extended her argument to suggest that "the various types of 'imagery' are optional coding strategies" (p. 119) in the sense that they are interchangeable. For instance imagining a rotation in terms of an arm or hand movement can provide just as adequate a basis for performance on a mental rotation task as imagining the rotation as if it was visually presented.

REPRESENTATION OF LARGE-SCALE SPACES

So far our discussion has focussed on studies performed in small scale spaces. A number of studies have compared visually impaired and sighted people's understanding of large scale environments. Golledge (1993) notes a number of commonalities in the learning of small-scale and large-scale spaces, such as hierarchical organisation and clustering. In contrast to the learning of small scale environments, which can be perceived at a single glance with vision but must be sequentially explored by touch, when learning a large-scale environment, visually impaired and sighted people alike are faced with the task of integrating information over time. In this important sense, the task of acquiring a representation of a large scale environment ('…one whose structure is revealed by integrating local observations over time, rather than being perceived from one vantage point.' Kuipers, 1982, p.203) is formally similar for the sighted and for the visually impaired. There are thus no a priori grounds for assuming that representations of large scale spaces acquired from vision or haptics-proprioception should differ in structure. For instance, within his model of spatial representation, Kuipers (1982) has stressed that *views* (the basic elements of the spatial representation) 'need not be visual images: A blind person's views could be auditory, tactile or even olfactory.' (p. 213) The integration of such elements into an environmental representation is in principle similar for visually impaired and sighted people.

However, the literature concerned with small-scale space indicates that visual experience has some influence on the way in which spatial information is encoded or organized, even when sighted controls perform the task blindfold. It is possible that such processing differences also apply to large-scale spatial tasks, even though the immediate task constraints are more similar for visually impaired and sighted people. Within the literature on large-scale environments, a few studies have focussed on the understanding of familiar environments but most have considered participants' ability to construct representations of novel environments, for example real buildings or experimental layouts.

Familiar Environments

Bigelow (1991) explored young visually impaired children's representations of the layout of their homes and neighbourhoods. Totally blind, partially sighted and sighted children in two age groups (mean ages: 4.7 and 6.0 years) were asked to point to locations in their homes and neighbourhoods, and their pointing responses were scored according to three criteria. The response was either in the Euclidean direction of the named location (Euclidean), along the first segment of the functional route to the location (route) or in neither of these directions. The partially sighted and sighted children mastered the tasks within the fifteen month testing period, mostly on the first session. In contrast, the totally blind children failed to master most of the tasks within the study period. Analysis of the children's errors showed that totally blind children more often pointed along the route to each location (route response) rather than towards the location itself (Euclidean response). This finding is supported by a number of studies (Byrne and Salter, 1983; Casey, 1978; Lockman et al., 1981; Rieser et al., 1980) using a variety of methods for externalizing the spatial representations of visually impaired and sighted adults of familiar environments, which found that the early blind tended to code the relative location of places according to their functional separation, suggesting a representation based on routes rather than an integrated configuration.

Ungar (1994, Experiment 4) examined the spatial knowledge of a familiar space in eighteen visually impaired children (aged 6 to 12.5 years). The children's judgements of the relative distance between nine locations in their school (see Figure 1) were tested using the method of triadic comparisons (Rieser et al., 1980). The locations were named in sets of three and each child was asked which two locations were the furthest apart, which two were the closest together (the intermediate pair can be inferred from these two questions). A balanced incomplete design was used (Burton and Nerlove, 1976) in which a set of forty eight triads were presented, each pair of locations appearing four times.

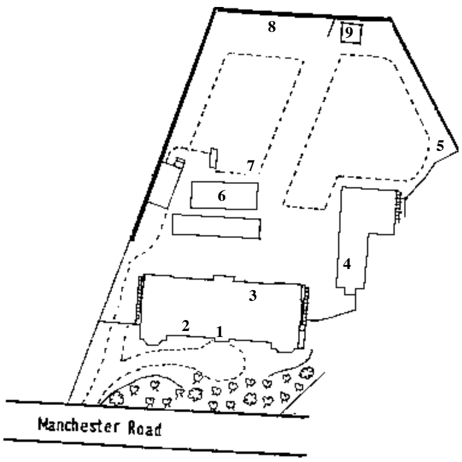

Figure 1: Layout of the school and grounds used to test children's knowledge of a familiar environment by Ungar (1994, Experiment 3) 1 - Entrance steps, 2 - Dining room, 3 - Staff room, 4 - Assembly hall, 5 - Skittle alley, 6 - Play area, 7 - Sand pit, 8 - Boat, 9 - Swings.

The pair judged to be furthest apart was assigned a value of 2, the pair judged to be closest together was assigned a 0 and the remaining pair was assigned a 1. Each child judged each pair of locations in the context of four different triads. The scores of these four judgements were summed to give an overall value ranging from 0 to 8 for each pair of locations (i.e. for each inter-location distance). Two sets of values were also generated for the 'ideal Euclidean participant' and for the 'ideal functional participant'. These were generated by completing the triads test on the basis of Euclidean and functional measurements taken from a scale map of the school and its grounds (the Euclidean distance is the straight-line or 'crow's flight' path between two locations whereas the functional distance is the normal path of travel between two locations).

Two error scores were calculated for each of the children, one relative to Euclidean distances and the other relative to functional distances. For each pair of locations the child's mean value was subtracted from that of both the ideal Euclidean participant and the ideal functional participant. This yielded two measures of error - one against a Euclidean baseline and one against a functional baseline.

Relative to the Euclidean baseline, the scores of the totally blind children were significantly higher (i.e. worse) than those of the children with residual vision. The analysis of scores relative to the functional baseline yielded no significant effects, but scores were generally lower for this analysis than for the Euclidean analysis.

Rank order correlations were performed to compare the distance judgements of each age and visual status group with those of the ideal Euclidean and functional participants. As Euclidean and functional distances are themselves intrinsically correlated, this correlation was partialled out. On the whole, children's relative distance judgements correlated more highly with the functional baseline than with the Euclidean baseline. However, in the case of the younger residual vision group, a correlation with the Euclidean baseline was obtained. The result from the younger residual vision group did not concur with the findings of Rieser et al. (1980) with adults. In their study, Rieser et al. found that both visually impaired and sighted adults' estimates correlated highly with functional distances unless participants were specifically instructed to give straight line distances (in the latter case, sighted and late blind adults shifted to Euclidean estimated while congenitally blind adults continued to give functional estimates).

Therefore, correlations were performed for each child's judgements relative to the Euclidean and the functional baseline. Apart from one child whose judgements were correlated with neither baseline, the judgements of all the children correlated with either one or other of the baselines but not both. Only four of the children made judgements which were correlated with the Euclidean baseline; all four had residual vision and three were in the younger group.

In order to gain some impression of the mental representations underlying children's relative distance judgements, the data were analysed using the multidimensional scaling procedure ALSCAL (SPSS release for the Macintosh). The input for this program is a matrix of dissimilarities - in this case judged relative distances - and the output is the two dimensional configuration of locations which best fits the input dissimilarities (i.e. the program comes as close as possible to the monotonic relationship between metric distance and ordinal dissimilarity between locations which would exist in a two dimensional space). While this representation does not necessarily provide a full externalization of a participant's mental representation of space it effectively displays a person's impression of the relative distances between locations.

For all participants taken together a picture emerged in which functional distances were exaggerated. We would also suggest (speculatively) that the functional distances were based on habitual paths of movement by the children which were observed over three years of the author's work at the school. The Entrance Steps and the Dining Room were represented as relatively close in space at the entrance to the school. Staff Room was represented as lying on the path from these to the outside. From the side entrance to the school, two paths appear to diverge which cross the expanse of tarmac playground behind the school. One of these leads to the Assembly Room block and the adjacent Skittle Alley, while the other leads to the Play Area and Sand Pit. A relatively shorter distance leads from the Assembly Hall / Skittle Alley group to the Swings and from the Play Area / Sand Pit group to the Boat. The Swings and the Boat were generally located relatively close together.

Overall the results were consistent with those obtained by Rieser et al. (1980) for adult visually impaired participants. In particular, the error scores for all groups were lower relative to the functional than to the Euclidean baseline and the children's judgements were highly correlated with functional distances in the space for all groups.

The MDS analysis provided a visualisation of the children's functional bias in estimating relative distances. The indoor locations were generally represented very close together while distances across the open expanse of the playground were exaggerated. This may be because children need to concentrate harder on maintaining a bearing across an open space than when walking along a corridor and thus distances across open spaces may be experienced as longer. Apart from these functionally exaggerated distances, the plots for the groups bore a close resemblance to the arrangement of the locations in the school suggesting that all the children had a good impression of relative distances from their extensive experience in the school environment.

When asked to estimate distances and directions in familiar environments, visually impaired children tend to respond on the basis of their functional experience of the environment rather than from an integrated representation. This result cannot be taken as evidence that visually impaired children are incapable of forming integrated representations of an environment as participants may have chosen to respond in this way although they were capable of providing straight line estimates. The fact that some of the children (some with very little sight) in the study described above spontaneously gave straight line estimates serves to underline this cautious interpretation of the results.

<u>Constructed Environments</u>

One problem in testing people's knowledge of familiar environments is that it is impossible to control for individual differences in experience. Rather than use familiar environments, 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, 1990) or an unfamiliar part of the real world (Dodds et al., 1982; Leonard and Newman, 1967; Ochaíta and Huertas, 1993).

Landau and her colleagues (Landau, 1986; Landau et al., 1981; Landau et al., 1984) carried out a series of studies with a single congenitally blind child, Kelli, between the ages of 3 and 5 years. In one study, Landau et al. (1984) familiarized Kelli with an experimental space (see Figure 2) by guiding her from a homebase position to one object and then from the homebase to the other object. Kelli was then led to the first object again and asked to walk to the second object. Kelli's trajectories were recorded on video and a number of measures were obtained from an analysis of the tapes, such as her initial heading as she left the first object and her final position. Landau et al. (1984) reported that Kelli's performance on the task was above chance and that she performed comparably to a group of blindfolded sighted children. Landau et al. suggested that Kelli was able to integrate information from the familiarisation phase into an overall impression of the relative positions of objects in the layout. In other words, that she formed a representation of the experimental space which was similar to that of the sighted children.

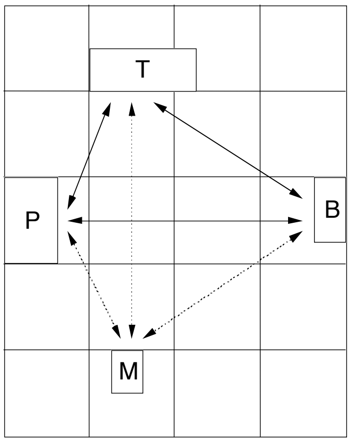

Figure 2: Layout used by Landau et al. (1984). M - Mother, P - Pillows, T - Table, B - Basket.

There have been several criticisms of Landau's methodology (Liben and Downs, 1989; Millar, 1988). Liben & Downs (1989) argue that Landau et al. (1986) overstated Kelli's accuracy in the inference tasks — for example Kelli's routes were not sufficiently straight to assume that she possessed accurate angular knowledge about the position of the target, and her distance errors were relatively large considering the size of the experimental room and the placement of targets. Millar (1988) pointed out that if Kelli was aware of or calculated the bearing of the target object at the outset of each route, one would not expect her to adjust her heading during movement. The fact that she did adjust her movement on many trials suggests that she had some means of updating her position and may have used sound cues or even some residual vision. In the light of these criticisms and the fact that only a single visually impaired child was tested, the results of Landau et al. (1984) should be interpreted with caution.

Another study with young children is reported by Rieser (1990). An experimental layout was constructed consisting of eight buckets evenly spaced around a four foot diameter circle. One of these (the target) contained an interesting toy. Totally congenitally blind children (22 to 44 months old) were led from the centre of the circle to the target bucket and allowed to play with the toy. Then the children were asked to step back from the target bucket, returning to the centre of the circle. After this the children were turned by the experimenter on the spot through either 90˚ or 270˚. The children were then asked to turn to face the target once again. All the children consistently reversed the rotation in order to face the target bucket despite the fact that the simplest solution in the 270˚ rotation condition would have been to continue turning in the same direction. In contrast, a group of sighted children tested in a darkened room consistently turned in the shorter direction to face the target. Rieser suggested that children coded their change in position in terms of their own body movement rather than in relation to the layout of external space.

Working with older children, Fletcher (1980) introduced visually impaired children and adolescents (7 to 18 years) to the layout of a room using either a scale model or direct experience. The participants' exploration of the space was either guided by the experimenter or unguided. Following exposure to the space, participants' knowledge of the room was tested with two types of questions, 'route' questions which tested participants' knowledge of spatial relations directly experienced during exploration and 'map' questions which required participants to go beyond their direct experience and infer spatial relationships between places not linked during exploration. For the congenitally totally blind children, accuracy was higher for route questions than for map questions — in contrast to a sighted control group who performed similarly on the two measures in a separate analysis — indicating that the congenitally blind children were unable to integrate information from their exploration of the room into an overall impression of the layout of objects.

Ungar et al. (in press, Experiment 2 - Exploration Condition) introduced congenitally totally blind and partially sighted children (aged 4 to 12 years) to a layout of six objects (see Figure 3) by walking them from a central point to each of the objects in turn, returning to the central point after each object had been visited. The children were then asked to aim a pointer from the central point to each of the other objects and from two of the object locations to all the other objects. Overall, the congenitally totally blind children were considerably less accurate than the partially sighted children.

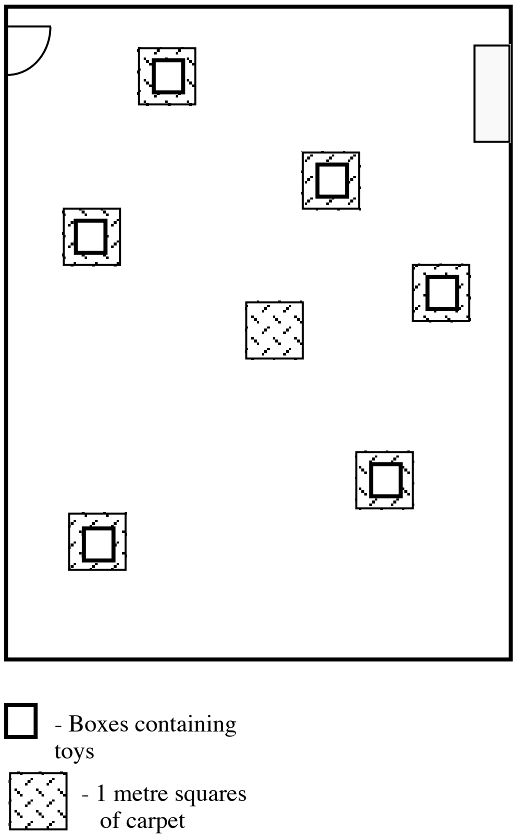

Figure 3: Example of the layout used by Ungar et al. (in press).

Novel Environments

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 coordinated 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 formed an egocentric or self-referent representation of the route, but were not able to form an overall survey-level representation of the layout.

In another study, Ochaíta & Huertas (1993) familiarized visually impaired 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. If a participant required assistance from the experimenter this was noted. At the end of each session, participants were asked to construct a scale model of the space and to perform a distance ratio estimation task based on the between - landmark distances. No differences were found between congenitally blind and adventitiously blind groups. However there were differences between the four age groups with only the older participant groups showing evidence of a coordinated representation of the travelled environment. Ochaíta & Huertas (1993) concluded that although congenitally blind participants achieved a coordinated understanding of the environment, their ability to do so was delayed relative to the established chronologies for sighted children (e.g. Hart and Moore, 1973). Ochaíta & Huertas suggested that the sudden increase in spatial understanding achieved by visually impaired children at adolescence may be due to 'the competence in abstract and propositional reasoning (which is assumed to be reached at this age)' and that '[it] is possible that in adolescence, verbal reasoning may 'remediate' some of the problems caused by the lack of vision in understanding figurative and spatial problems' (1993, p.40).

Strategies for Coding Large-Scale Layouts

The studies reported above might be taken to imply that visual experience is necessary for forming coordinated, survey representations of the environment. However, such an interpretation would ignore the possibility, emphasised by Millar (1988), that alternative (non-visual) spatial coding strategies might be available to visually impaired children who are provided with appropriate experiences. The use of alternative coding strategies was highlighted in a study by Rieser et al. (1982; 1986). They 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. 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 early blind performed both conditions at the same level which the other groups achieved in the imagination condition

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 by the groups with and without visual experience. 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. 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.

Although the study of Rieser et al. (1982; 1986) is interpreted within a Gibsonian framework, their results and interpretation provide some support for Millar's (1988) model of sensory deprivation, as the congenitally blind participants apparently brought to the task modes of encoding spatial information which differed from those used by the sighted participants. However this model does not distinguish between Fletcher's (1980) Inefficiency and Difference theories; it is possible that the preferred strategies of people who have had no visual experience of space are necessarily inferior or less efficient for performing spatial tasks. Some light is thrown on this distinction by the fact that some of the early blinded participants in the Rieser et al. (1982; 1986) task performed identically to the other groups in terms of both errors and latencies. If we assume, with Rieser et al. (1982), that these individuals were necessarily using different strategies for performing the task from the later blind and the sighted participants, this finding would provide support for the Difference theory; these participants may have been using different strategies which were functionally equivalent to (i.e. just as efficient as) the strategies of the participants whose performance was based on previous visual experience.

However, Loomis et al. (1993) in a replication of the Rieser et al. (1982; 1986) study failed to reproduce the pattern of errors of the earlier study; there were 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 were higher than those of the sighted which would suggest a speed/accuracy trade-off consistent with the use of a calculation strategy by the visually impaired participants.

Overall, the evidence for a general spatial impairment in early blinded children is inconclusive. It appears that task and procedural differences can result in poorer performance by early blind groups or similar performance between early blind and sighted groups. Furthermore in most of these studies, individual visually impaired participants performed well within the range of sighted and late blind groups. Thus a strong Deficiency theory can be rejected. It seems more plausible that there are differences in the ways of coding space between groups or even between individuals which are more or less appropriate or adequate for the task demands.

CODING SYSTEMS RE-EXAMINED

The distinction between self-referent and external coding strategies has been subjected to much analysis in previous research. It has been argued that young children are bound to egocentric spatial coding systems which are supplanted by external reference systems later in development (Piaget and Inhelder, 1956; Piaget et al., 1960; Siegel and White, 1975). Piaget's (Piaget and Inhelder, 1956; Piaget et al., 1960) theory of the development of spatial cognition also assumes that visually impaired children's reduced opportunities for interaction with objects in the environment would result in a delay in the acquisition of higher level, non-egocentric spatial representation (see Fraiberg, 1977). A number of studies indicate that early blinded people, even in adulthood, are generally restricted to a representation of the environment at the route level (i.e. in terms of sequences of landmarks or decision points). Carreiras & Codina (1992) have termed this latter position the 'visual representation hypothesis' because it implies that vision is necessary for the formation of configurational representations of the environment. A sequential representation, while permitting efficient travel along well known routes, does not easily support inferences about the relative locations of places not linked in a learned route; this information would have to be actively calculated at the time of retrieval and this could impose severe limitations on a person's mobility.

Three types of evidence suggest that a rigid Piagetian model is inadequate. Firstly it has been shown that even very young children can use external cues to code object positions when the experimental setting makes those cues highly salient for the children and therefore there is no reason to propose two distinct modes of encoding space, one (external or geocentric) which supplants the other (egocentric) at some point in development (Acredolo, 1982; Bremner, 1978; Presson and Ihrig, 1982; Presson and Somerville, 1985; Rieser, 1979). Secondly, it is clear that self-referent coding strategies are used by adults when it is appropriate to do so, for instance when external cues are unreliable (Millar, 1988; Presson, 1987). In this respect, Millar (1988) cites the example of a person sitting in a train looking out of the carriage window as the next-door train begins to move off. Here it is egocentric (vestibular) information which tells us that we are not moving. Thirdly, Millar (1988) argues that congenitally blind children, rather than exhibiting a delay in an invariant developmental sequence of levels of spatial representation, are simply using strategies which are most appropriate to the performance of the majority of spatial tasks in the absence of vision.

Carreiras & Codina (1992) have termed the alternative position the 'amodal representation hypothesis' which they characterize thus:

> It is assumed that internal spatial representation is not linked to any specific sensory modality. According to this hypothesis, blind persons are able to preserve and process spatial images in a similar way to that used by sighted persons, although such processing may require less time when vision is involved. If given sufficient training, blind persons are assumed to be able to acquire a configurational spatial representation, and solve spatial problems with strategies similar to those employed by sighted persons (p. 55).

This theory leaves open to speculation the possibility that the early blind can acquire representations or coding strategies equivalent to those of people who have had visual experience, if they are given sufficient training, preferably from an early age (Juurmaa, 1973; Millar, 1988). The amodal representation hypothesis suggests that there would be differences between visual experience groups at the stage of constructing representations of the environment, but all the studies carried out in novel environments have controlled exposure to the experimental layouts such that all groups received the same quality and quantity of experience in them. In the studies of familiar environments it cannot be known how the groups differ in experience of independent mobility. It is recognized that lack of vision imposes limitations on a person's independent mobility and thus, although the early blind might require more experience of an environment to acquire representations equivalent to those of the sighted. It is possible that the visually impaired participants in the studies described above had less independent experience than the sighted.

It seems likely, from the foregoing discussion, that the construction of spatial representations may be mediated by a number of optional (i.e. interchangeable) strategies each of which may be more or less adequate for a given spatial task. This suggests that visually impaired children can form coordinated global representations of the environment if they can be encouraged to use the appropriate (i.e. externally based) coding strategies. A number of possibilities for interventions to facilitate the spatial cognition of the visually impaired have been discussed and some of these will be presented in the next section.

EARLY INTERVENTION

That visually impaired people clearly have the potential to achieve the same level of efficiency in spatial tasks has been shown in the study of Rieser et al. (1982; 1986) and in a number of other studies in which visually impaired individuals performed at or even above the level of sighted participants in spatial tasks (Casey, 1978; Dodds et al., 1982; Fletcher, 1980). However group comparisons in these and other studies often show that the early blind are impaired relative to the sighted on many spatial tasks, especially those conducted in large scale spaces which involve locomotion (Rieser et al., 1982; 1986; Rieser et al., 1980; Ungar et al., in press). Thus it would seem that in general the coding strategies or spatial representations of the early blind, while adequate for many small scale tasks, are generally inadequate, or at least inappropriate, for large scale tasks. Warren (1984) draws the following implications from the literature:

> In order to make available to the child the widest range of effective strategies of spatial information processing, he or she must be brought to dissociate strategies from modes of experience and their natural constraints. Tactual experience, for example, must be structured in such a way as to lend itself easily to external reference systems, so that those systems become flexibly available to the child, along with the internal ones (p.88).

Warren suggests two lines of research which should be pursued to find effective methods of remediation. Firstly, an attempt should be made to identify the aspects of early experience which give rise to differences in the ways in which children code spatial relations. Secondly, procedures should be devised to train visually impaired children to use an external spatial framework or to form configurational representations. Similar recommendations have been made by Millar (1988), Juurmaa (1973) and Carreiras & Codina (1992) among others. Juurmaa in particular stresses the importance of intervention from the earliest years. So far no research has been carried out in the first of these areas but a number of methods have been proposed to facilitate the development of children's understanding of the relationships between objects in the environment.

Training children to be more aware of their 'body image' (Cratty and Sams, 1968) is one of the main traditional methods thought to facilitate the development of spatial cognition in young blind children. The conceptual basis for this method is the belief that once a child has mastered concepts such as laterality, verticality and the arrangement of objects in space with respect to her own body, these will form the basis of an understanding of space external to the child. Although such techniques are widely used by Orientation and Mobility teachers they have not been adequately validated and one recent study (Morsley et al., 1991) suggested that there is in fact no relationship between a child's body image and her general spatial skills.

Another approach has been to substitute vision with an electronic device which converts optical information about objects in the environment into auditory or tactile information. One such device, the Sonicguide™ has been used in several studies with visually impaired infants and young children. It was hypothesized that providing children with auditory information about objects and surfaces in external space from and early age would facilitate their general understanding of the environment. In one study by Aitken and Bower (1982; 1982) 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 (1984) cited a number of studies with similarly inconclusive results.

Another potential means of bringing the layout of external space to the child is through a tactile map. A tactile map can provide a vicarious source of spatial information which 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 compensate to some extent for the limitations of the visually impaired, they may form a crucial component of mobility training (Gilson et al., 1965; Yngström, 1988).

Tactile maps may have important benefits in both the short term and in the long term. Liben (1981) draws a distinction between 'abstract' and 'particular' levels of spatial thought, the former refers to a person's ability to construct and use mental spatial representations, while the latter refers to the quality of a person's representations of specific environments. Tactile maps can usefully be used to introduce children to particular spaces, such as a classroom or a play ground, but the use of maps in general, and in particular the exercise of relating maps to the environment which they represent, can improve the child's abstract level spatial thought in the long term, for instance by encouraging the child to adopt externally based coding frameworks for structuring spatial representations of the environment.

RESEARCH ON TACTILE MAPS

Most of the existing research related to tactile maps has been concerned with the design and production of such maps (e.g. Aldrich and Parkin, 1987; Bentzen, 1977; Bentzen and Peck, 1979; Berlá, 1981; Dacen-Nagel and Coulson, 1990; Horsfall and Vanston, 1981; Parkin et al., 1988). In recent years a few studies have considered how visually impaired adults and adolescents use a map (Andrews, 1983; Berlá, 1973; Berlá and Butterfield, 1977; Berlá et al., 1976; Berlá and Murr, 1975; Brambring and Weber, 1981; Dodds, 1988; Gladstone, 1991; Golledge, 1991; Spencer and Travis, 1985) or a model (Carreiras and Codina, 1992; Fletcher, 1980; Herman et al., 1983).

Research with Adults

Carreiras & Codina (1992) asked congenitally blind, blindfolded sighted and sighted adults to explore a model of layout of streets with a number of places (landmarks) represented by discriminably textured pins. The adults were asked to make distance estimates between places on the model; both functional (route) and straight line (map) distance estimates were required. In order to be accurate on straight line distance estimates, the adults had to infer configurational level information from their sequential exploration of the model (as for Rieser et al's [1982; 1986] 'experimental' questions and for Fletcher's [1980] 'map' questions). There was no difference between the groups on the estimation of functional distances but the congenitally blind group was less accurate than the sighted groups on straight line distance estimates.

The studies by Carreiras & Codina (1992) and Fletcher (1980) (reported above) examined the mental representation of a tactile model but did not address the problem of transferring such information to the space represented by the map. Only a few studies have examined the spatial behaviour of visually impaired people who have learnt about a space from a tactile representation (i.e. a map or a model). For example, Herman, Herman & Chatman (1983) asked visually impaired teenagers and adults to learn a large-scale layout of four objects from a table-top model. The participants' knowledge of the layout was tested by asking them to walk between locations in the large-scale space. The results suggested that the congenitally blind participants could form a configurational representation of the layout from the model which they could then use to navigate in the real space. However Warren (1984) has pointed out that the errors of these participants were very high and may not have been different from chance levels. Therefore the experiment of Herman et al. (1983) does not provide unambiguous evidence that transfer from the model to the real space occurred.

Bentzen (1972) introduced six congenitally and adventitiously blind adults to a novel environment (the campus of the Perkins School for the Blind in Boston) using a tactile map of the area. The participants were asked to travel a planned route carrying the map. Though there were too few participants to perform statistical analyses, Bentzen reported that all the participants completed the route with a high degree of accuracy and two of the six participants completed the route without help from the experimenter. The other participants became disoriented at least once, but were able to pick up the route when led back to the correct course.

In a similar study, Brambring & Weber (1981) asked 27 'blind' participants to learn a novel built environment (a network of streets in Marburg) using either direct exploration, a verbal description or a tactile map of the area. The participants were then required to walk certain routes in the area. It was found that participants learned the area more quickly and their wayfinding performance was better with the map than with the other methods of familiarisation.

Overall, studies in which visually impaired adults suggest that tactile maps can facilitate the construction of cognitive maps. Furthermore, tactile maps may be a more effective means of familiarizing visually impaired people with an environment than direct locomotor experience. Tactile maps can apparently provide the visually impaired reader with a more integrated and global impression of the environment.

Research with Children

Gladstone (1991) presented three congenitally blind children (9, 12 and 13 years of age), five congenitally blind adults and 12 blindfolded sighted adults with tactile maps of routes varying in overall length (8 metres or 16 metres) and route complexity (two turning points or six turning points) and allowed them unlimited time to learn each map. Participants were then taken to a large empty space and led from the origin point to the first turning point of a given map to demonstrate the scaling factor between that map and the large scale space. They then returned to the origin point and were asked to walk the route that they had just learned. This procedure was repeated for sixteen different routes.

Visually impaired and sighted participants took the same amount of time to complete each type of route. Overall, the visually impaired adults made more accurate turns (absolute angular error) than the visually impaired children and sighted adults on all types of route. Visually impaired children were as accurate in turning as the sighted adults on the short and long routes and were only slightly less accurate on the complex maps. Therefore, Gladstone's (1991) participants clearly could transfer information from the map to behaviour in the environment. Although Gladstone's task involved carrying the map and thus did not require forming a survey representation of the experimental space, all the visually impaired participants reported forming 'a representation of the map as a whole' (p. 31). Four of the visually impaired adults and all the children reported 'using a strategy of counting steps and relating this to the distance on the map' (p. 31).

Given the fact that several authors have stressed the importance of introducing maps and map concepts to children from the earliest possible age (Gilson et al., 1965; Kidwell and Greer, 1972), it is surprising that there has been little consideration given to whether *young* visually impaired children might benefit from using a tactile map.

One of the very few studies with young children was by Landau (1986) who asked Kelli (at four years of age) was asked to use a simple map of an experimental space which depicted her own position and the location of a target object. Kelli's performance in walking to the target was above chance level indicating that she could use the map to determine the location of the object in space and Landau (1986) concluded that blind children from as young as four years may be able to understand and use a simple map to guide movement through the environment. She suggested that this ability is directly supported by the 'spatial knowledge system' which is used for other spatial behaviour. This claim is akin to the proposition that maps are 'transparent'— windows on the large-scale environment — which simply specify the spatial relations between places with minimal requirement for interpretation.

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. 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 (Spencer et al., 1989; Spencer et al., 1992; Ungar, 1994; Ungar et al., 1993; Ungar et al., in press; Ungar et al., 1992).

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., in press). 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 map. 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.

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, 1994; Ungar et al., 1992) it was found that the strategies which 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.

Studies on the use of tactile maps by visually impaired children have produced similar results to those with adults. Tactile maps can provide visually impaired children with an impression of the layout of the environment and thereby facilitate the construction of accurate and integrated cognitive maps. This finding is particularly significant considering the relatively poor performance of visually impaired children in forming coherent cognitive maps from direct experience on the environment. If visually impaired children are trained to use tactile maps effectively, they might form the basis for improving the general spatial skills of these children and in particular the construction of cognitive maps.

CONCLUSION

This chapter summarized research related to the construction of spatial representations of the physical environment in visually impaired children. The evidence from groups of early blinded, late blinded and sighted children suggests that visual experience facilitates the construction of spatial representations. However, we have argued that visual experience may not be a necessary requirement for the ability to form integrated, global impressions of the environment. Rather, children's modes of experience of the world may prompt the use of different strategies for coding information. These strategies are interchangeable (i.e. a tactile strategy could replace any given visual strategy) but strategies are more or less appropriate or effective for certain tasks.

If visually impaired children can be encouraged from an early age to adopt appropriate strategies this will improve the quality of their spatial representations. For instance, for learning the layout of large-scale environments, visually impaired children should be encouraged to adopt an external reference system rather than one based purely on their bodies or their own movements. We have discussed two means (electronic aids and tactile maps) by which visually impaired children can be encouraged to code the positions of objects in the world relative to each other.

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