THE DEVELOPMENT OF SPATIAL KNOWLEDGE AND ORIENTATION

Alison M. Conning

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Declaration

This thesis is the unaided composition of the author and is a record of research carried out by the author. It has not been previously submitted for any degree or diploma to any institution.

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The Resolution and Regulations of the University of St. Andrews relating to the degree of Doctor of Philosophy have been fulfilled by the author.

Dr. R.W. Byrne (Supervisor)

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"I should see the garden far better", said Alice to herself, "if I could get to the top of that hill: and here's a path that leads straight to it - at least, no, it doesn't do that -----" (after going a few yards along the path and turning several sharp corners), "but I suppose it will at last. But how curiously it twists! It's more like a corkscrew than a path! Well, this turn goes to the hill I suppose - no, it doesn't! This goes straight back to the house! Well then, I'll try it the other way".

Lewis Carroll, Through the Looking Glass
Chapter 2.

Of course the first thing to do was to make a grand survey of the country she was going to travel through. "It's something very like learning geography", thought Alice, as she stood on tiptoe in hopes of being able to see a little further.

Lewis Carroll, Through the Looking Glass
Chapter 3.

ABSTRACT

This thesis describes a series of experiments which investigate preschool children's spatial abilities. To overcome the problems of extrapolating from traditional laboratory task to abilities in the real world, the children were tested in 'natural' environments, such as buildings and streets, and which were large-scale, that is, they could not be viewed in their entirety from one position but instead had to be constructed from successive views. The measure of spatial knowledge chosen was direction estimation, a task which has been successfully used by other authors with older subjects, and which avoids the problems of interpretation and comprehension inherent in more traditional methods of investigating spatial representation such as map drawing and model building.

The findings are discussed in relation to Piaget's distinction between topological and Euclidean spatial knowledge (Piaget et al. 1960; Piaget and Inhelder 1967; Piaget 1977), but traditionally used interpretations of his theory are avoided (e.g. Siegel and White 1975) as being based upon methodologically problematical experimentation. The results are interpreted in terms of Byrne's (1979, 1982) network-map/vector-map theory of spatial knowledge, which has only previously been applied to adults.

It was found that preschool children can show both network-map knowledge (topological), and vector-map knowledge (Euclidean). Piaget's stage theory of development is inappropriate as within the age and ability range tested here, the type of spatial knowledge

shown was more dependent upon qualities of the environment than of the child. Preschool children are most likely to show vector-map knowledge in small, over-learned, and actively explored environments than in larger passively explored but familiar environments, and lastly in novel large environments. Preschool children's network-map knowledge, built up by walking in natural environments, is coded in one direction only; and two separately learned but overlapping routes are encoded as an integrated network.

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CHAPTER 1

Introduction and theory

Until recently, the vast majority of investigations of children's spatial knowledge have been carried out within the broad framework of Piaget's theory of spatial development (Piaget, Inhelder and Szeminska 1960; Piaget and Inhelder 1967; Piaget 1977), or theories based upon it. The following chapter will outline these theories, examine whether their claims have been substantiated by the experiments of other authors, and then present a more appropriate framework within which to examine children's spatial knowledge, namely Byrne's (1979, 1982) theory of network-map and vector map knowledge. This thesis focuses on the spatial abilities of preschool children, between the ages of two years and ten months to five years and three months. The following discussion of previous work in this area will therefore concentrate on this age group.

I Theory: previous theories of spatial development.

The most widely used interpretation of Piaget's theory of spatial development is that of Siegel and White (1975). They state that development proceeds from 'route knowledge', to 'minimaps', and finally to 'survey maps' (Shemyakin 1962) once an objective frame of reference has developed. 'Route knowledge' is the kind of knowledge expected of preschool children, for whom it is based strongly on their own movements. It includes path choice at landmarks, and knowledge of the sequence of landmarks to be encountered. 'Minimaps' are similar to Piaget's 'fixed frame of reference' (Piaget et al. 1960) In both, one has knowledge of the relative locations of objects which are near each other in a small cluster, and such knowledge is based on relating each of these objects to a fixed reference object, but one has no knowledge of the relative positions of individual clusters. For example, a child might know where three friends' houses are relative to her house because they live nearby; and where the park and her favourite sweet-shop are relative to her Granny's house; but she may have no idea where Granny's house is relative to her own house, even though Granny may only live a few streets away. 'Survey map' knowledge develops when the child has an overall coordinated system of spatial referents that is independent of individual landmark locations or the child's own position in the setting, and means that the previously separated 'clusters' are accurately related to each other. Siegel and White (1975) suggest that adult knowledge goes through these stages when one is building up information about a new area, but that young children of different ages are unable to express knowledge beyond a certain level; for example, preschool children can have route knowledge only. The various strands of the developmental sequence are related in Table 1 which has been compiled from Siegel and White 1975; Hart and Moore 1973; Piaget and Inhelder 1967; Piaget et al. 1960.

The nature of the preschool child's spatial knowledge according to this developmental sequence will now be examined more closely. Although age is flexible, and invariance of the sequence of development is more important, Piaget's preoperational child is generally

Developmental Stage	Mode of Representation	Frame of Reference	Types of topographical representations	Types of spatial relations
Preoperational	Motoric	Egocentric	Route maps	Toplogical
Concrete operational		Fixed	Mini-maps	Still topological; some projective and Euclidean relations, but uncoordinated
Formal operational	Internalized/ symbolic	Objective/ coordinated	Survey maps	Additional projective and Euclidean relations of proportional reduction to scale, accuracy of distance and metric coordinates

Time

Table 1 Spatial Development

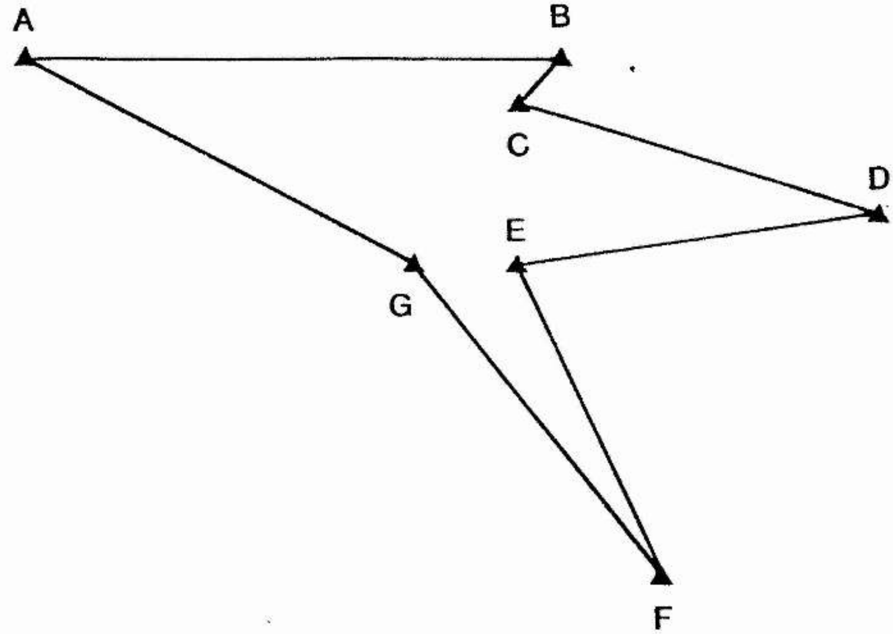
regarded as being between the ages of two years and seven years. The preschool children studied in this thesis therefore fall well within the usual age span of the preoperational child. One feature of preoperational knowledge is that it is static, in the sense that children concentrate on the states of a situation and not on its dynamic transformations, so their knowledge cannot be manipulated. To take a classic example, if seven sweets are laid out in one-to-one correspondence with seven pennies, preoperational children will agree that they are equivalent. But if the seven sweets are compressed to make a short line while the line of seven pennies remains the same so that the two sets are still equivalent in number, preoperational children notice only that the line of pennies is now longer than the line of sweets while ignoring the fact that the line of sweets is denser, and conclude that there are now more pennies. They do not reverse the act of rearrangment, and instead attend to states not transformations; that is, preoperational children's thought lacks reversibility. In terms of spatial knowledge, preoperational children are unable to reconstruct a route in the reverse direction, or to rotate a plan through 180 degrees (Piaget et al. 1960).

Piaget suggests that preoperational children have an egocentric frame of reference. This means that the positions of objects are defined with reference to their own body. For example, a child standing with his or her back to the door may learn that the window is on the right hand side. However, if he or she moves to the other end of the room and faces the door he or she would still expect the window to be on his or her right hand side. A feature of spatial egocentrism is that children are unable to predict what a visual display would look like from another person's view, and expect that the other person will see the same view as themselves. From Table 1 it can be seen that preoperational children's knowledge of space is topological, by which it is meant that they code no information about angle or distance between locations, but will preserve such relations as 'next to', openness and closedness (Piaget and Inhelder 1969). The implications of this for children's spatial knowledge are illustrated in Fig. 1. Preoperational children's spatial knowledge is 'motoric': it is based on remembering their own actions when moving along a route, and landmarks are tacked on to these recollections, where 'by rights the motor schema should fall back on the landmarks' (Piaget et al. 1960, p.12). The actions remembered are such things as 'from the church head for the post office', and not the nervous messages sent to the limbs as the term 'motor' could imply.

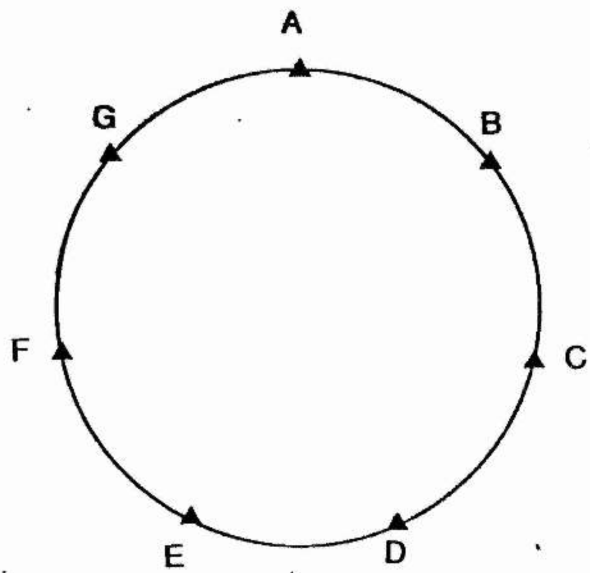
Experimentation based on Piaget's theory of spatial development, and Siegel and White's (1975) interpretation of this theory, have largely looked at the frame of reference used by children (egocentric, fixed, coordinated), the types of spatial relations encoded (topological, projective and metric), the mode of representation (motoric, internalized and symbolic), and the nature of the representation which results (route map, mini-map, survey map). Each of these strands of the theory will be examined in turn in the light of experimental evidence. However, it should be remembered that Piaget's theory was based largely upon evidence from children doing modeling tasks, and so may not be appropriate for their behaviour in

Fig. 1 Implications of topological coding for the child's spatial knowledge

Actual route may be:



Child codes:



Closedness and route proximity have been preserved, but not actual angle and distance between locations.

the real world.

A. Frames of Reference: the egocentric preoperational child.

Piaget's theory of spatial egocentrism appears to be based largely on his interpretation of Meyer's 'Three Mountains' experiment. An account of this can be found in The Child's Concept of Space (Piaget and Inhelder 1967), but it will be described in some detail here because it is often misquoted. In this experiment, children aged between four years and twelve years were shown a model of three distinctively different mountains. There were three tasks, 1) to place a doll where it could take a photograph corresponding to one shown to child, 2) to select from an array of pictures the photograph which the doll could take from where the experimenter had placed it, and 3) to construct what the doll saw using three boxes. Meyer found that for task 1) above, 'the doll is placed anywhere at random or simply left in the same place all the time, because the child thinks the doll can see the three mountains from any position, regardless of perspective' (Piaget and Inhelder 1967, p.213); in other words, for the child, any place from which the doll can see all three mountains is as good as any other. For task 2) above, preoperational children either select the picture corresponding to their own view, or select a picture at random, because 'so far as the child is concerned, all the pictures are equally suitable for all points of view, so long as they show three mountains' (Piaget and Inhelder 1967, p.213). Only for task 3 above, when the child has to build a model of the doll's view of the three mountains, do all the preoperational children show the mountains from a single point of view: their own view. Nevertheless, it is claimed that all three tasks support an interpretation in terms of spatial egocentrism: such a claim exceeds the results (Morss 1983). In this same volume, Piaget argues for the first time that the child's initial understanding of space is of a topological nature, with projective and metric systems being achieved later. Morss (1983) argues that this theory is incompatible with spatial egocentrism because the transition from the topological to the projective system occurs when, or because, the child becomes able to construct one viewpoint from many, with constructing one's own viewpoint only being perhaps the first sign of this ability, and therefore a fairly advanced form of responding; whereas, for the theory of spatial egocentrism, it is the earliest form of response. The theory of preoperational children as topological responders clearly fits the findings of Meyer's 'three mountains' experiment more closely than the theory of spatial egocentrism, as at least for tasks 1) and 2) above, most of the children believe that any view from which all three mountains can be seen is as good as any other. Morss (1983) therefore argues that Piaget retained his theory of spatial egocentrism by mistake.

Nevertheless, a vast amount of research has been based upon Piaget's theory of the young child as spatially egocentric, and this will be examined below. Each author has presented a slightly different task, thus producing slightly different results. I will therefore try in what follows to sift through this sea of data and extract common themes. The research falls into three main categories which will be examined in turn: a) table-top models, b) larger environments, and c) map use or map-making tasks.

Ai. Table-top models

These experiments all use table-top spatial displays which alter one or more of the features presented by the three mountains experiment. Together they test children between the ages of nine months and eleven years, and have the common purpose of trying to show that altering the nature of the task changes the response of the child; or rather, that children do not respond egocentrically if the conditions are changed. The main variations used are as follows. Firstly, one can change the nature of the display objects. It has been found that displays with fewer objects (Fishbein, Lewis and Keiffer 1972; Millar 1981; Rosser 1983), more discrete objects (Borke 1975; Fehr 1978; Millar 1981), toys with no distinct front, back or side (Gullo and Bersani 1983), or familiar objects (Fehr 1978; Millar 1981) all reduce the number of egocentric errors young children make. Secondly, one can change the nature of the task: it has been found that even three year olds make less egocentric errors when they have to turn the whole display so that they see what the doll saw, rather than when they have to select the picture which corresponds to what the doll sees (Borke 1975; Fishbein et al. 1972). Other authors have found that two or three year olds do not make egocentric errors when they move around the covered display and have to predict how the display will then look (Shanz and Watson 1971), or if they are moved around the display and have to find a target which they previously saw hidden at one of four locations (Lasky, Romano and Wenters 1980). Several authors have directly compared the children's responses after rotation of the display and self-rotation (Bremner 1978; Huttenlocher and Presson 1973;

Presson 1980). There seems to be a general agreement that egocentric errors are more likely to be decreased when the child moves, even if the child is as young as nine months. Other methods of altering the nature of the task have been to make it have more 'human sense' (Donaldson, 1978); for example, Donaldson (1978) reports a task devised by Hughes in which even children as young as three years and five months were able to coordinate the views of two toy 'policemen' and find a hiding place for a 'boy' doll where he could not be seen by the policemen. It is argued that this was because the children knew what it is to be naughty and to want to evade the consequences, that is, the motives and intentions of the characters are comprehensible even to the three year olds. It has also been found that covering the display before the child responds increases his or her chances of being able to coordinate perspective (Shanz and Watson 1971; Walker and Gollin 1977). Thirdly, the actual test environment itself is important, as Acredolo (1979) has found that nine-month old infants can respond nonegocentrically in an object location task when tested in their own homes, but not when tested in a bare laboratory or in an unfamiliar but landmark-filled office. Fourthly, it has been suggested (Light and Nix 1983) that four to six year old children only choose their own view when it is a good view of the display, so the selection of a good view has priority over selection of one's own view.

The results of all the experiments described above suggest that, given the right situation, even children as young as nine months can respond non-egocentrically on table-top tasks. In order to bring success, the tasks decrease the demands made upon the child, and increase their likelihood of using the external frame of the room to make their response. To relate this to the theory of development from topological to projective and metric knowledge, the experiments described above only really provide evidence that the young children understand that different people can have different perspectives of the same view. In most of the tasks, Piaget's original experiment which required true projective knowledge has been changed so much that they are soluable by an understanding that different people at different positions do not have the same view of the display, plus the use of topological cues (Russell 1982), such as those provided by the framework of the room. As illustration, consider those tasks in which the child moves around the display. As the child moves, all he or she has to remember is that item A is next to the wall with the picture on it, item B is next to the window, and so on. The objects remain in invariant relationships to one another throughout the task, both in terms of relative position and orientation, so all the child has to know is the order in which the objects will appear from different perspectives, and this can be solved using topological knowledge. This is a very different task from photo-selection, as the photographs do not show the positions of the objects relative to the frame of the room; and different again from the children having to construct the view from cardboard shapes, as this involves knowing the orientation of each object, its position relative to the other objects, and the view from which the doll will see the display. All that can be concluded from this section is that even very young children do not necessarily respond egocentrically when tested on table-top displays. To investigate whether their knowledge is truly projective, or reliant upon topological cues, specific manipulations of the cues available need to be made. Experiments which do this will be examined below. However, it does seem that what develops is the ability to predict another's view in tasks which are more and more difficult (Braine and Elder 1983), for example, because the positions of more objects have to be coordinated relative to each other and to the frame of the room.

Aii. Larger Environments

These experiments differ from those described in the previous section in that instead of the experimental display being 'table top' sized and placed in a larger room, it is large enough to walk through and uses the whole of the room. The experiments use a variety of methods, so it is probably best to examine them according to the age of the child tested, rather than by experimental method. Testing of infants below two years of age has involved the infant anticipating the occurrence of an event in a certain location (Acredolo 1978; Presson and Ihrig 1982). Acredolo (1978) taught six month, eleven month and sixteen month old infants to turn their head to one of two windows, placed either side of the infant and experimental room, when a buzzer sounded in anticipation of the appearance of the experimenter at one of the windows. When the infants were turned through 180 degrees, the six and eleven month old infants responded egocentrically, that is, they continued to make the same movement; whereas the sixteen month old infants were able to compensate for their change in position and so turned their heads correctly to find the experimenter. However, this cannot explain whether the younger infants were coding the position of the experimenter egocentrically or whether they had not attended to their changed position, perhaps because their movement was passive. Nevertheless, Acredolo (1978) found that the addition of a landmark to cue the position of the appearance of the experimenter had little overall effect, with its greatest impact being upon the eleven month old infants. This experiment could be seen as evidence that six month old infants code location entirely with respect to themselves, that is, egocentrically, whilst the eleven month old infants are beginning to be able to use an objective frame of reference when topological cues are obvious, whereas this ability is well developed in the sixteen month olds; however, the results could also be because the cue used was not salient to the six month old infants. Presson and Ihrig (1982) have shown that even infants as young as nine months do not always rely on egocentric cues. Infants seated next to their mothers were trained to expect a slide to appear on their right or left. The infants were then rotated to a place 180 degrees away, and were tested to determine which direction they would look to anticipate the next slide. For half the infants, mother moved with them to the new position, whereas for the other half mother remained in the same place throughout the training and test periods. It was found that those infants whose mothers remained in the same position throughout made less egocentric responses, and seemed to be using mother's position as a cue to their response. Perhaps mother is the first objective cue to spatial location that infants learn to use.

Tasks with young children, rather than infants, tend to involve active movement of the child within the environment, rather than just anticipation of a event by a head turn. The experiments will be examined in chronological order of age of the subjects tested. Acredolo (1976) looked at whether three and four year olds rely on egocentric cues, object cues, or container cues. The meaning of these will become clearer as the experiments are explained. In the first test she led three and four year olds blindfolded on a route round a room which was bare except for a table at the start of the route. Whilst the children were blindfolded, the table was silently moved from one side of the room to the other. Half the children ended their walk where they came in, and half ended it at the 180 degree reversal of this place. The blindfold was then removed, and the child asked to return to the start. It was found that the three year olds made an egocentric response (walking to the right) wherever they had ended the walk; whereas, the four year olds used an object frame of reference, and went to the table. A second test was then carried out on three year olds, four year olds, and ten year olds which was the same as before except that the walls were distinguished with coloured curtains, and there was a third condition in which the table stayed in the same position, but the child ended the walk at the other end of the room (180 degree reversal). This time it was found that none of the children made egocentric responses, however, the ten year olds were significantly more likely to rely consistently on the container cues, that is, the coloured walls, than were the three or four year olds, some of whom showed consistent dependence on the object frame of the position of the table. So why no egocentric responding in the second test? Acredolo (1976) suggests that this was because the room was smaller and so more easily learned by the three year olds. Nevertheless, the results suggest that children as young as three years do not have to respond egocentrically, and the type of reference which young children use is determined by the specific situation of the test. The influence of landmarks on young children's egocentric responses was shown in two tests carried out by Acredolo (1977). Three, four and five year olds learned the location of a hidden trinket in a small square room in which there were either no landmarks; individual landmarks in the form of a red circle being behind the subject's original position, and a black tringle hung behind her test position; or direct landmarks in the form of distinguishing cloths covering the two tables upon which the two cups were placed which did or did not contain the trinket. A simple association between cup and cloth could then be formed, and the trinket could be found using a topological response. It was found that in the absence of any landmarks, the three and four year olds, but not the five year olds, made egocentric responses when tested from the 180 degrees position. In a second test, the children were told to remember that they had changed places, but only the four year olds benefitted from these instructions. So egocentric responses (repeating the initial movement made) are made by young children in the absence of any landmarks to aid their orientation. However, repeating the initial movement made is surely very different from Piaget's original use of the term to refer to the inability to pick a picture or build a model corresponding to another person's perspective. A task more truly a larger scale version of the three mountains experiment is that of Herman, Roth, Miranda and Getz (1982) who tested the ability of five to six year olds, and eight to nine year olds to replace seven toys in a large area from a position congruent with the encounter position (0 degrees perspective), or from a perspective 180 degrees opposite the encounter point. They found that recall from 180 degrees perspective led to a significant decrease in memory for specific locational information, but not for the general configuration. However, none of the children made egocentric errors, and the authors suggest that the children could have used cues from the room. This conclusion seems likely as, when Weatherford and Cohen (1980) encouraged eight and nine year olds to view the whole of a similar display in relation to the containing room, perspective taking was facilitated.

Hardwick, McIntyre and Pick (1976) asked six, ten and twenty-one year olds to imagine they were moving round a learnt room from point to point whilst hidden behind an occluding screen, and to aim at several learnt target locations. They found that the six year olds were unable to carry out this mental manipulation and imagine what the room would look like from each of the other points, and so either responded egocentrically (that is, they pointed as if from their actual location rather than as if from their imagined location) or they pointed chaotically. All of the subjects found the task harder when the occluding screen was removed so that the actual perceptual information conflicted with their imagined visual display. The authors found that the ability to carry out this mental manipulation increased with age. However, the results may have little to do with the subjects' ability to imagine another perspective, and more to do with their ability to understand the experimental instructions, or the ability to hold in mind at one time the positions of all the points and all the targets.

In conclusion of this section, it seems that even children as young as nine months can know that a change in their own position within an environment alters the position of certain objects or events relative to themselves, so they are not egocentric in that sense. However, success at locating the 'new' position of the object or event relative to themselves depends upon the specific test situation, and the kinds of cues which are available. A closer look at the nature of the cues used will be taken in the section below on topological coding.

Aiii. Map use and map-making tasks.

Young children's ability to coordinate perspective has been investigated in some experiments which go far beyond the methodological example provided by Piaget, and look at young children's ability to use maps rotated in relation to the experimental space, to build maps, or to recognise the aerial view of an environment. All three kinds of tasks demand knowledge of a perspective which cannot be directly perceived by the child. The map using tasks test children between the ages of three and eight years. The earliest of these was carried out by Bleustein and Acredolo (1979) who asked three, four and five year olds to read a simple map to find a hidden object. The map was presented to the child either congruent to the experimental space, or at 180 degrees to it; and was presented either inside or outside the test area. They found that most three and four year olds were unable to find the target with the rotated map, and more egocentric errors were made when the rotated map was presented inside the test area, because the subjects were influenced by the spatial array in front of them. So it seems that three and four year olds (indeed, like many adults!) are unable to mentally rotate the information provided by the map to find the target; however, I do not think that one can conclude from this that three and four year olds are unable to coordinate perspectives. Firstly, when they were given the rotated map within the test area, the results show that they were unable to override the perceptual information they were receiving from the room, not that they cannot coordinate the rotated map and the test environment. Secondly, when they were given the rotated map outside the test environment, their failure could have been due to inability to hold the rotation in memory, and not inability to coordinate the rotated map and the test environment or to reverse the rotation per se. In a similar experiment, Presson (1982) asked five and eight year olds to use a map to find a target hidden in one of three large containers. The map was read either inside or outside the hiding area; and was either aligned with the space (0 degrees), or rotated 90 degrees or 180 degrees to the experimental space. Both age groups performed well on the 0 degree trials, whether the map was read inside or outside the experimental 'room'. All the children found the 180 degrees condition more difficult than the 90 degrees condition which was not significantly different from 0 degrees. However, when the five year olds read the rotated map inside the experimental area, like Bleustein and Acredolo's (1979) youngest children, they made egocentric errors. This could not have been due to coding spatial information solely in relation to self, as that would have caused errors outside the experimental room as well, but was probably because the children were unable to ignore the perceptual information they were receiving from the room, and so directly related the map to the room without making the rotation. The fact that Landau (1982) found that a five year old congenitally blind girl could use a 180 degree rotated map to guide her locomotion to a target provides extra support for five year olds' ability to coordinate perspectives in the absence of conflicting perceptual information.

Map building tasks, although fraught with problems of interpretation and validity (see Chapter 2) can perhaps reveal something about the nature of children's frames of reference. Hart (1981) asked children to build a model map of the area around their home and school, and concluded that even the four year olds were able to use a 'fixed' frame of reference, as they used their home as a base from which to recall the relative location of important objects and places; and that even six and seven year olds would produce 'survey' type clusters for the areas that they are allowed to explore on their own, as opposed to the areas they are only allowed to visit with older children. It therefore seems that the nature of the child's frame of reference is largely dependent upon the qualities of the environment, or the child's interaction with that environment.

Many studies have shown that young children can interpret an aerial view of an area, even though they have never seen the environment from that perspective before. For example, Blaut and his colleagues have shown that children as young as five years can recognise features on an aerial photograph, and even make a map by tracing from the photographs which they can then use to solve a simulated navigation problem (Blaut, McCleary, and Blaut 1970; Stea and Blaut 1973a, b), and it is hypothesized that environmental toy play may have an important role in developing this ability (Blaut and Stea 1971). However, other authors have shown that even younger children can relate an aerial perspective to their normal view of the world. Three and four year olds, even though they cannot explain the aerial perspective, or say how the picture was made, can recognise features on an aerial photograph (Spencer, Harrison and Darvizeh 1981). Children of twenty-five months but not nine months, can use information provided by an aerial view to traverse a maze and find their mother, showing that they realise the aerial view was a different view of the same space (Rieser, Doxsey, McCarrel and Brooks 1982).

From this section, it can be concluded that even children as young as twenty-five months can relate an aerial view of an environment to their more usual view. When children have to both interpret a map and rotate the information in order to find a hidden target, children below the age of five find the rotation difficult, and tend to respond 'egocentrically' because they cannot override the perceptual information they are receiving from the environment itself. This is not to say that they can only use an egocentric frame of reference, but rather that heavy task demands and/or conflicting information reduce their chances of success. Hart's (1981) map building task suggests that the frame of reference used by children is largely dependent upon the nature of their interaction with the environment.

Aiv. Conclusions about frames of reference

In conclusion, the wide range of methods used to investigate young children's frames of reference, suggest that the preoperational child is not egocentric in the sense of not understanding that the same environment will look different from different perspectives. Instead whether the young child will make an 'egocentric' response or not is largely dependent upon the nature of the test, such as the number of relationships that have to be coordinated, the kinds of cues which are available, and whether there is conflicting perceptual evidence. If sufficient cues, or landmarks, are available even young infants can use these as opposed to self-reference, and the evidence points towards the suggestion that preschool children rely more heavily on objects as reference points than older children who may be able to use the frame of the whole room to coordinate perspective. Nevertheless, there is also some evidence that the type of reference used by the child is dependent upon the nature of the environment (for example, Acredolo 1976), and the child's interaction with the environment (Hart 1981). It may therefore be that children respond egocentrically by picking their own view, or repeating a previous movement, when the task demands exceed their capabilities (for example, because of the amount of information which they would have to hold in memory at once exceeds their capacity) and so they do not know how else to respond as in the original three mountains task; and not because they do not realise that the same display will look different from different perspectives. Correctly deciding what these other perspectives will look like is dependent upon the type of cues available, with younger children relying more heavily on object cues than older children.

B. Types of spatial relations: the preoperational child's reliance on topological relations.

Piaget presents two kinds of experiments from which he draws his conclusions that development proceeds from topological knowledge to projective and metric knowledge of space. In The Child's Conception of Space (Piaget and Inhelder 1967) he presents a series of table-top or paper and pencil tasks designed to look at each stage of development. His investigation of the topological stage primarily made use of drawings, tactile perception (that is perceptions by touch, without vision), and tests of the understanding of linear and circular order using beads on a string. The understanding of projective properties was investigated by such techniques as observing children's ability to construct straight lines using a number of discrete objects, getting them to draw various perspective figures, asking questions about the projection of the shadows of objects, and the relations between objects perceived from different points of view. The transition from projective to Euclidean concepts was investigated by looking at the children's understanding of transformations preserving parallels, of similarity and proportion in figures such as the rectangle and triangle, and of systems of horizontal and vertical reference axes. For example, children were asked to replace a doll in a rotated model landscape, to draw objects from certain viewpoints and on a reduced scale, and to reproduce a model village using real objects. It must be borne in mind, however, that children's performance on such tests may not be relevant to their understanding of, and performance in, the real world. In The Child's Conception of Geometry (Piaget et al. 1960) an experiment was carried out which is more relevant to the child's knowledge of real-world space, as investigated in this thesis. The children were taken individually into the experimental room attached to their school, and asked to look through the window from where they could point out various buildings and well known places. This was 'merely to ascertain the extent of his local knowledge and sense of direction' (Piaget et al. 1960, p. 5). The children then sat with their back to the window and made a model of the school buildings and principal features round about, using a sand tray, model houses and various other oddments. They then had to reconstruct a route from school to a well-known landmark; and change the location of the features once the school building had been turned through 180 degrees. It was found that early preoperational children (Stage IIa: about 4 years) were unable to arrange the pieces of the model in any systematic way. The middle preoperational children (IIa to IIb: about 4 to 6 years) could only represent topological relations. They ignored distances and perspective relations; and there was no coordination between the arrangement of objects and the external reference systems provided by the sand-tray on which they lay. Latter preoperational children (IIb: about 5 to 7 years) can arrange two objects, but rather than relying on spatial proximity they tend to use such things as conceptual similarity or subjective interest to make their response. But they failed even with these rules if three or more objects were involved. At the onset of the concrete operational period (IIIa: about 7 to 8 years), the beginnings of general projective and Euclidean coordination developed, but it was not until the development of formal operations (IV: about 11 to 12 years), when the concept of a coordinated reference system was attained, that the projective and Euclidean relations of proportional reduction to scale, accuracy of distance, and metric coordinates, were taken into account (Hart and Moore 1973). However, this experiment may underestimate the children's abilities for two reasons: firstly, when they turned their backs to the window to perform the task, they had to build a model whose orientation was not congruent with the view they had just seen; and secondly, some of their difficulty may lie in the process of model building per se which requires scale reduction, and is viewed from above rather than on the same plane as the real world. Will spatial abilities still appear to develop in stages from topological to projective and metric knowledge when larger-scale environments and tests are used, and which do not involve translation of scale and a vertical perspective?

Three kinds of experiments which investigate the types of spatial relations used by young children in larger-scale environments will be examined: small-scale constructions of large-scale environments, reconstruction of walk-through environments, and large-scale experiments. 'Large-scale' means environments which cannot be viewed from one vantage-point, and so have to be reconstructed from several views (Acredolo 1981). 'Walk-through environments' are, as the name suggests, large enough for the child to walk through, such as a large model town placed on the floor of a room, but the whole display can be viewed from one vantage point, and so does not have to be reconstructed from several views. 'Small-scale environments' are table-top size, and so the whole display can be seen at once, and they are too small for the child to walk through the environment.

Bi. Small-scale model or 'map' construction

In these experiments, children were asked to build or draw 'maps' of a particular environment. For example, Piché (1977) asked five to eight year olds to make models and maps of a learned town environment, and concluded that development during those years proceeds from imitation of real displacements (the child's actions), to the structuring of actions into groupings which conserve the topological properties of space, and then to the structuring of groupings which conserve the projective and Euclidean properties of space. However, other authors have found rather different results for children's knowledge of their home area. For example, Biel (1979) found that half of his six year olds, when asked to draw a map of their home environment, could produce a good over-all configuration in as much as only one place deviated significantly from the cartographic map, if, to do this, they could hold on to a continuous spatial representation. The other half used topological relations only. The ten year olds would all use metric and Euclidean relations. It is possible that the advanced knowledge shown by half of the six year olds was because their house was used as a personally salient landmark around which other parts of the environment were cognitively organised (Biel 1982b). A similar argument is presented by Hart and Berzok (1982) who suggest that the ability of a four year old, Christopher, to configuratively map his house, favourite tree, and road by placing objects on a large sheet of paper was because he was mentally placing himself inside his home and recreating what he could see. They suspect that such a strategy could only be used for sets of places that had been perceived simultaneously. However, they also found that the 'survey' or Euclidean type clusters produced on the model maps of children under eight years all fell within the children's 'free range', that is, the places they were allowed to explore alone or with their peers without permission (Hart and Berzok 1982). Such data seem to suggest that although in general development proceeds from topological to projective and Euclidean knowledge, the type of knowledge displayed by a child is dependent also upon the nature of the environment, and the child's previous interaction or familiarity with that environment. Even the maps of adults become Euclidean only with increased experience (Evans, Marrerro and Butler 1981).

Bii. Reconstruction of walk-through environments

Herman and Siegel (1978) carried out two experiments with five, seven, and ten year olds, which asked them to reconstruct a model town on the floor of a room, using models 6.4 centimetres or 11.4 centimetres high. In the first, they found that even the five year olds could accurately reconstruct the model, including those buildings which had minimal topological cues, suggesting that they had some Euclidean knowledge. However, there were strong indications that the children of all ages were relying on topological cues, as they all placed isolated buildings less accurately than buildings with clear topological positions. Nevertheless, a second experiment showed that the younger children's reliance upon topological cues was greater than that of the older children because, when the task was carried out on an area in the middle of a gym, so that the town was less closely bounded by the walls, and there were no topological cues provided by desks pushed to the edge of the room, the five year olds performed less accurately than in the first experiment, whereas the older children were less affected. Reliance upon topological cues does therefore seem to decrease with age, but the fact that the five year olds were able to construct accurate models in the first experiment, implies that the children must at least have rudimentary knowledge of Euclidean space, aided by topological cues, as the use of topological knowledge alone would not be sufficient for such accurate placing of the objects.

Distance reconstruction tasks have been used to explore children's Euclidean knowledge. For example, Cohen, Weatherford, Lomenick and Koeller (1979) taught seven to eleven year olds a route between fifteen locations in one room. In another, empty room they had to perform three distance estimation tasks: a magnitude estimation task (How many steps is it between X and Y?) a straight-line-reconstruction task (place two cards on the floor in a designated direction, to display the distance separating two objects), and a free-reconstruction task (place two cards, in any direction, to represent the distance between two objects). They found that the eleven year olds were equally accurate on all three tasks, and that the seven year olds were only as accurate as the older children under the free reconstruction conditions. The knowledge of the older children is therefore more flexible, suggesting that their mastery of projective and Euclidean properties is greater than that of the seven year olds.

Biii. Large-Scale Experiments

Large-scale experiments have provided some evidence that older children are less dependent on topological cues than younger children. Acredolo, Pick and Olsen (1975) asked three to eight year olds to find the location where they had previously seen a card being dropped by an experimenter. In a landmark rich environment the three and four year olds did not perform significantly worse than the eight year olds, but in an undifferentiated environment the three and four year olds were significantly less accurate than the eight year olds. However, this heavy reliance upon topological cues may be because of the limited experience the children were given with the environment. When tested in their home area, children as young as six years can make internally consistent and accurate estimations of the distances between two landmarks (Biel 1982a). Even five year old children can display metric knowledge in some conditions, as for example, a five year old congenitally blind child can use the metric information given by a simple map to guide her locomotion to a target (Landau 1982).

The ability to make inferences, that is, to infer the relationship among parts of the environment between which subjects have not directly travelled, is sometimes used as a measure of Euclidean knowledge. Hazen, Lockman and Pick (1978) found three to six year old children poor at making spatial inferences after learning a route round a configuration of four or six small rooms. However, Lockman and Pick (cited in Pick and Rieser 1982) found that even four year olds were quite good at making inferences about targets behind walls in their own apartments if the targets were on the same floor as they were standing. It therefore seems that the nature of the environment plays a part in determining young children's knowledge.

Biv. <u>Conclusions about development from topological to projective and metric knowledge</u>.

The experiments described in this section indicate that young children are less likely to show Euclidean knowledge, and more likely to show topological kowledge, than older children. However, the evidence also suggest that even very young children can display Euclidean knowledge to some extent in certain situations, perhaps because of their familiarity with the environment, or because of the nature and degree of their previous interaction with that environment. Even for adults, the extent of their Euclidean knowledge depends on the amount and nature of their previous interaction with a particular environment (Moar 1979), and it may even be that truly Euclidean knowledge is rare in adults rather than being the usual form of representation (Byrne 1979; Moar and Bower 1983).

C. <u>Mode of Representation: the motoric representation of the preschool child</u>

From their model building experiment described above, Piaget *et* al (1960) concluded that preoperational children's spatial knowledge is based on remembering their own actions when moving along a route, and that landmarks are tacked on to these recollections. By this they did not of course mean remembering the action of moving each limb, but such things as at the church continue walking towards the post office. What young children say when they are performing spatial tasks often suggests that they are indeed relying on recollections of their own actions. For example, Biel (1982b) found that the majority of the six year olds he tested said they made their distance judgments in their home area by thinking out their actual walks in the environment. Nevertheless, one cannot rely on subjective reports as an indication of mode of representation (Byrne 1982): Biel's six year olds accurately judged the actual distance between locations in their home area, and did not seem to be relying on the walked distance. Two kinds of evidence will be used to examine whether children's spatial knowledge is 'motoric' in nature: experiments which look at reliance on functional or walked distance rather than direct distance, and studies which look at how the nature of children's spatial experience effects the knowledge they can build up of a particular environment, and their spatial abilities in general.

Ci. Reliance on functional distance.

There is some evidence that young children rely more heavily on functional distance than adults. For example, Anooshian and Wilson (1977) performed an ingenious experiment in which five year olds and adults watched a train travel round a board from object to object. Although the objects were the same distance apart, the train tracks either made a direct route or an indirect route between the objects.

The test was to place similar objects on a board with no tracks. They found that, even if the train took longer to travel the direct routes than the indirect routes, five year old children but not adults placed the objects that were connected by longer tracks farther apart than those connected by direct tracks. However, these findings may not be relevant to situations in which the child actually does the movement between locations. Several experiments have looked at the effect of barriers which prevent direct movement between locations on subjects' estimations of distances. For example, Kosslyn, Pick and Fariello (1974) taught four to five year olds, and adults the locations of objects in a room divided by two transparent and two opaque barriers. They then had to rank from memory the distance between all pairs of objects. It was found that children perceived objects separated by both types of barriers as farther apart than objects separated by the same distance with no barrier; that is, their judgments were based on the functional or walking distance between objects. The adults' perception was distorted only where objects were separated by opaque barriers. However, this effect of barriers is not quite so straightforward as was first thought. Both the amount of experience with the environment, and the strength of the task demands, affect the responses given. Increased motor experience with the route between the objects has been found to decrease reliance on functional distance, not increase it as would be expected if young children's representations are entirely motoric in nature. For example, Cohen and Weatherford (1981) found that five to eight year olds, and ten to twelve year olds, were able to compensate for the potentially distorting effects of barriers in conditions which provided either an extended experience of the environment, or repeated experience with a single path. Barriers led to distortion in estimates when the individual had limited experience which was distributed across different paths (which is surely what happens in many real life situations); and the effect was more pronounced for barrier-present distances which were not directly walked but simply viewed than for barrier present distances which were walked directly. However, functional distance and direct experience of a route do not influence distance estimations in a simple fashion, as, for example, seven, eleven and twenty year olds' distance estimations were more accurate when the route between locations had been travelled, was long, and had no intervening barrier, than when the route was not travelled, was short, and had intervening barriersto prevent direct travel (Cohen and Weatherford 1980). Indeed, it has even been suggested that the distorting effect of barriers has little to do with the influence of the walked route, but rather is the result of barriers serving as boundaries or borders dividing a space into subsections. Preoperational children may then judge distance according to the topological qualities of enclosure and belongingness imposed by the barriers, rather than on metric qualities (Acredolo and Boulter 1984).

There is, however, some evidence which suggests that adults do not always perform more accurately than children, and that it may be limitations in processing capacities which cause the differences in responses. For example, Newcombe and Liben (1982) found that on a rank ordering task in which the subjects had to keep the entire spatial layout in mind simultaneously, six year old children, but not adults relied more heavily on functional distance than crow-flight distance. However, with the same children, on a direct estimation task in which only two locations had to be held in mind at once, there were no differences between the performance of adults and children. If the number of locations to be remembered is increased sufficiently, so that the demand on the subjects' processing capacities is also increased, then adults will show a pattern of response like those of children, that is, their estimations are biased towards the functional distance in the presence of both transparent and opaque barriers (Liben 1982).

In conclusion, it seems that both adults and children make distance judgments which are distorted by the presence of barriers in some situations. But given enough experience with an environment, and a task which does not place too great a demand on their processing capacities, even five year olds can make crow-flight distance judgments. The difference between adults and young children therefore seems to be that the children are more limited as to when they will be able to show knowledge of crow-flight distance.

Cii. The nature of the environmental experience

Experiments which explore the effect of the type of environmental experience on children's spatial knowledge have looked at many different aspects of the experience: the number of walks through an area, walking versus looking, walking versus riding, and self-directed versus other-directed movement. In what follows, an attempt will be made to collate the findings from these differing studies.

There is some evidence that repeated trips through a model town increase the accuracy of five, seven and ten year olds spatial knowledge of that environment (Siegel, Herman, Allen and Kirasic 1979), but this may not be due to the motor experience per se, as repeated viewing of a model town can lead to equally accurate spatial knowledge in five, seven and ten year olds as repeated walking through the town (Herman and Siegel 1978). At least for eight year olds, it is important that the way in which their spatial knowledge is displayed is congruent with the activity performed during exposure to the space, that is, both should be active, or both passive (Cohen, Weatherford and Byrd 1980). This is not so true of ten to thirteen year olds, whose knowledge is more flexible. Several authors have looked at the effect of walking round a route versus being carried or riding round a route on children's spatial knowledge. For one year olds and three year olds, Heth and Cornell (1980) found no significant difference in the children's goal finding abilities whether they had learned the route by walking round it, or by being carried. However, when the children watched their parents walk the maze, both age groups could choose the correct route from the start, so their performance was better than when they directly experienced the environment for themselves. This result may be because very young children do not need to pay attention to their own movement, as they are usually carried or led around, whereas paying attention to an adults' movement may be vital if the children do not want to lose sight of their parents. However, children from five years upwards are more likely to have accurate spatial knowledge, both in the laboratory (Herman, Kolker and Shaw 1982), and in the real world (Bishop and Foulsham 1973), if they have walked through the environment, than if they have ridden.

Motor experience alone may not be enough for accurate spatial knowledge of an environment, as several studies have shown that whether the movement is self-directed or not is important, especially for young children. For example, Feldman and Acredolo (1979) found that active exploration resulted in greater accuracy in returning to the place where a key had previously been found for three and four year olds, but not for nine and ten year olds who were equally accurate in both conditions. Similarly, the self-control of movement facilitated the interlocation distance estimates of five year olds, but not of eight year olds (Poag, Cohen and Weatherford 1983). However, in contrast, in a large model town experiment, Herman (1980) found that both five to six year olds, and eight to nine year olds had significantly less accurate spatial knowledge after they had directed their own movement through the area, than after the experimenter had directed their movement, which suggested that children need experimenter direction in order to attend to relevant cues. This difference may be due to the increased number of objects to remember in Herman (1980) (eight as opposed to five in Poag et al. 1983, or one in Feldman and Acredolo 1979) or because the task of replacing all the objects in the model town is more difficult than making distance estimations, or finding one location. When data has been gathered on children's knowledge of the real world, it seems that, at least for six and eight year olds, their most accurate knowledge is found for those areas around their home which they are allowed to explore freely and independently (Biel 1982a, 1982b; Hart 1981).

There is some evidence that motor experience with the environment affects children's abilities on spatial tasks in general. For example, three to seven year old boys of the Logoli tribe (Munroe and Munroe 1971), and five to eight year old boys of the Gusii tribe both in East Africa (Nevlove, Munroe and Munroe 1971), seem to do better on spatial tasks such as copying block patterns than age-matched girls, perhaps because they are allowed to range further from home. However, in Britain, Webley (1981) found that although eight year old boys had more extensive ranges than girls of the same age, this did not affect the detail of the spatial knowledge which the boys were able to build up. Thus, in contrast to the Munroes' experiments, extensive movement through the environment did not lead to superior spatial ability in the boys. This may reflect differences in the tests given to the children in these studies, or be because children in Western society are able to gain from other relevant experience, such as play with scale toys, or it may be due to the extent of the difference between girls' and boys' ranges. Nevertheless, there is some evidence that motor experience affects children's ability to learn novel routes as, for example Spencer and Darvizeh (1981b) found that those three and four year olds who walked to play-school did significantly better on novel route-finding tasks than those children who came by car or bus; and Piché (1977) suggested that a wide range of exploration helps five to eight year olds to learn new routes quickly. It therefore seems that motor experience does not change the nature of young children's spatial knowledge per se, but perhaps develops their tendency to look for and remember landmarks, and sequences of landmarks along routes. However, it should be borne in mind that adults' abilities are also affected by the extent and nature of their geographical experience (see, for example, Murray and Spencer 1979; Thorndyke and Goldin 1983).

In conclusion, it seems that, at least for children of five and over, active, self-directed exploration increases their spatial knowledge of a particular environment (as long as there are not too many objects to remember), and may increase young children's ability to learn novel routes. However one cannot therefore conclude that young children's spatial knowledge is based on remembering their own actions. All the studies show is that active involvement with the spatial world increases spatial knowledge.

Ciii. Are landmarks tacked on to young children's recollections of their own actions?

Part of Piaget's theory of the motoric nature of preoperational children's representations is that landmarks are tacked on to their recollections of their own actions. Siegel and White's (1975) elaboration of Piaget's developmental sequence differs with Piaget on this point, as they believe that firstly landmarks (by which they mean 'unique patterns of perceptual events at a specific location' which are 'strategic foci to and from which one travels' (Siegel and White 1975, p.23)) are noticed and remembered, and that children's actions are then registered with reference to the landmarks leading to route knowledge. A similar debate has gone on with reference to the order in which adults build up knowledge of a new environment, but here experimental evidence for the order of children's acquisition of knowledge only will be considered, as the two processes need not necessarily be identical.

In defence of Piaget, Piché (1977) has concluded from her interviews with five to eight year old children that landmarks are indeed tacked on to recollections of children's own actions. For both proximate and distant space, she found that the children first reflected on their own displacements and actions, and only later added a few environmental landmarks to their displacements. However, young children's ability to talk about places and routes may be a very different thing from how they actually behave, so evidence from experimentation must also be considered. For example, Darvizeh and Spencer (in press) found that landmarks had a key position in three and four year olds' newly learned routes, as they were unable to complete the route if one or more landmark was lost, suggesting that their route knowledge is dependent upon landmarks, although this does not of course mean the landmarks <u>predate</u> route knowledge. Similarly Cohen and Schnepfer (1980) found that when seven, eleven and twenty-three year olds had to recall routes along corridors which they had previously learned from slides, the seven year olds knowledge was seriously disrupted when the artificial landmarks of toys were removed, whereas the eleven year olds could recall the routes with or without the toys. The evidence therefore suggests that even though young children may not talk about their movements in relation to landmarks, their knowledge involves memory of them.

Civ. <u>Conclusions about the motoric representation of the preschool</u>

child.

The evidence suggests that increased motor experience with an environment, especially if it is self-directed, increases the child's knowledge of an environment. However, this is not evidence that children's representations are therefore only in the form of thought out actions. For example, this increased motor experience with the environment can help even the young child gain direct distance knowledge. Dependence upon the walked route may be the result of excessive task demands rather than the inability to infer direct distance. Nevertheless, when the child is learning a route, knowledge of landmarks is an integral part of the process.

D. General Conclusions

From Piaget's work (Piaget and Inhelder 1967; Piaget *et al.* 1960; Piaget 1977), and the theory of Siegel and White (1975), one would have to conclude that the preoperational child's spatial knowledge is in the form of a topological route map, based on an egocentric or self-reference system, and coding nothing about distance or direction. Only later could the child form 'mini-maps' based around a single fixed locus of reference, and it is not until the adult form of thinking develops that 'survey' or configurational maps are formed, with a coordinated frame of reference. However, the experimental evidence discussed above suggests that even young infants are not egocentric in the sense that they understand that the environment looks different from different perspectives: their ability to work out what the other perspective looks like depends upon the demands of the task but may lack true projective ability. It also shows that although development proceeds in general from toplogical to Euclidean knowledge, even young children can apparently show accurate Euclidean knowledge under some conditions, perhaps because of the nature and extent of their previous interaction with the environment. Although increased motor experience enhances young children's spatial knowledge, the results of this experience can be metric or Euclidean spatial knowledge, so the young child's representation is not merely motoric. It appears that with increasing age, the child's chances of displaying knowledge at one of Siegel and White's, or Piaget's, more advanced levels is increased, but that is not to say that young children are incapable of some features of Euclidean knowledge but rather that the type of knowledge they display is dependent upon the nature of the environment, and type of interaction they have with that environment. It seems, therefore, that development does not proceed through a series of discrete stages, as Piaget's theory would imply, but rather that what develops is the ability to display advanced spatial knowledge in more and more situations. This thesis will look more closely at the types of environments and experiences which affect the level of children's spatial knowledge.

Although the majority of research into children's spatial knowledge has been based on Piaget's theory of spatial development, or Siegel and White's (1975) interpretation of the same, the present author considers that a more appropriate model could be found, both because of the apparent unsuitability of a strict stage theory of development, and because Siegel and White's (1975) developmental sequence is inadequately defined. Their model does not explicitly define the point at which knowledge of direction and/or distance becomes part of the representation. For example, are route maps always plans of actions or can they encode precise information about the angle and/or distance of the path between landmarks? Are minimaps any different from small-scale survey-maps? Are survey or configurational maps merely networks of topological routes, which derive their apparent spatial nature 'second hand' by the joining and ordering of these routes; or do they actually encode precise information about the angle and distance between locations?

II Theory: Byrne's Network-map/Vector-map theory of spatial knowledge.

Byrne (1979, 1982) has proposed a theory of spatial knowledge which answers the criticisms of Siegel and White's (1975) model. He suggests that there are two possible kinds of spatial representation: network-maps and vector-maps. The model is devised for describing "memories of large-scale spatial areas which are typically acquired by personal experience" (Byrne 1982 p239). His use of the term 'map' should not be taken as implying that the mental organisation of this knowledge has properties like those of a cartographic map, but is merely used as a convenient terminology (Byrne 1982). 'Network-maps' encode routes as networks of strings, each string being a program for locomotion enabling travel from start to finish. Nodes along the string identify physical locations, and may also contain instructions for changes in direction at choice points. When several routes are known from a single choice point, then the string becomes branched. Although Byrne does not do so, it may be helpful to distinguish between branched and unbranched programs by calling the former 'network-maps' and the latter 'string-maps'. Byrne's (1979, 1982) network-maps are topological in nature, containing no precise information about angle or distance between locations, and therefore a subject possessing only network-map knowledge would rely on heuristics such as 'distance is equivalent to the number of nodes between locations' and 'any turn is a right angle'. Byrne's (1979, 1982) network-map theory was in part inspired by computer-based theories of semantic memory, and indeed uses the 'spreading activation' concept (Collins and Loftus, 1975) to describe how routes between specified pairs of locations are accessed. In this, 'activation spreads out from start and end nodes at a constant rate in a metric where 'distance' corresponds to nodes, so that the 'spheres' of activation first meet on a pathway which connects the start and end with the fewest number of intervening nodes', (Byrne 1982 p 246). However, this presumably does not imply that strings are meant to be two-way, as this would be a misuse of the program metaphor. If the route is known in both directions then it would be coded as two strings. Network-maps are not the same as Siegel and White's (1975) 'route knowledge', as network-maps can branch, and are exclusively topological, whereas neither of these points is explicitly defined as a quality of route knowledge. Instead route knowledge is apparently unbranching and could be either topological or encode information about angles turned and distances travelled. Network-maps appear to bear a strong resemblance to the topological knowledge Piaget considers to be characteristic of preoperational children: both depend on the walked route, encode no precise information about angle or distance between locations, and rely on heuristics as, for example, Piaget suggests that 'the distance between objects is dismissed altogether where these are held together by subjective interest' and 'conceptual similarity is mistaken for proximity in space' (Piaget _et al_. 1960). Unlike network-maps, 'vector-maps' encode horizontal information about direction and distance, and so in this respect are isomorphic to the real world when viewed from above. They are not the same as survey or configurational maps, which, as we have already seen, may not explicitly code this type of information, but could derive their apparent spatial nature 'second hand' by the joining and ordering of routes. Byrne's

(1979, 1982) vector-maps bear a strong resemblance to the Euclidean spatial knowledge which Piaget considers to be characteristic of children of about nine years of age and older (Piaget _et al._ 1960; Piaget and Inhelder 1965; Piaget 1977), and which preserves angle and distance. The early stage of this in which children have knowledge of the relative locations of objects which are near to each other and which can all be related to one reference point, could be viewed as _small_ vector-map representation. However, Byrne's and Piaget's theories differ in some respects. Piaget ties his topological and Euclidean knowledge to specific stages of development, whereas Byrne's theory was developed from findings about adult's spatial knowledge, and makes no predictions about the development of young children. This thesis will apply Byrne's theory to young children's knowledge for the first time. His theory is chosen in preference to the topological - Euclidean dichotomy presented by Piaget because it is more clearly defined, because the present author's interpretation of the literature suggests that a stage theory is inappropriate, and because the use of Piaget's theory is open to misinterpretation by those who cannot disentangle what he proposed from the explications of subsequent authors.

CHAPTER 2

Methodology: previous methods used to investigate children's spatial knowledge.

Children's spatial knowledge has been investigated by a wide range of methods, which differ both in how the spatial information is acquired, and in how the mental representation is interrogated. In what follows, the problems and limitations of each method will be examined, and arguments will be put forward to support the methodology used in this thesis. It will be suggested that young children's spatial knowledge may have been underestimated previously because of the tools of investigation used.

A. How spatial information is acquired

Ai. Natural acquisition

Some investigators have looked at children's knowledge of environments which has been acquired naturally. This could involve testing the children in an already familiar environment, such as their own classroom (Liben, Moore and Golbeck 1982; Golbeck 1983), or their home area (Biel 1982a). Or else, the experimenter might present the children with a novel environment, such as a museum room, but impose no control over their investigation of it, except perhaps in the time allowed for exploration (for example, Hazen 1982; Henderson, Charlesworth and Gamradt 1982). The former method is the only one possible for investigating children's knowledge of their everyday environments, but is limited by individual differences in method of exploration and time spent in a particular environment, which will not be known to the experimenter. The latter method is ideal for investigating these individual differences in exploration, and their affect upon spatial knowledge. However, one has to decide what constitutes 'natural acquisition' as young children will learn some environments such as their own houses by active, self-exploration; whilst others will be learned via adult-guided movement, such as the route from home to playgroup.

Aii. Table-top displays

Researchers into young children's spatial knowledge have sometimes looked at their performance on table-top spatial arrays which are not meant to be models of real environments (for example, Piaget and Inhelder 1967; Smothergill 1973; Kearins 1981). Although such experiments are interesting in their own right, and can provide information about children's memory strategies in recalling such displays for example, one must be careful in inferring findings from such studies to children's knowledge of, and behaviour in, the real world. Acredolo (1977) compared three and four year olds' ability to find a location after an 180 degree rotation in a room-sized environment, with the same test performed on a half metre square board, and concluded that behaviour was not isomorphic in the two tests.

Aiii. Model villages

Some investigators have taught children 'walk-through' sized model villages (for example, Herman 1980; Herman, Kolker and Shaw 1982; Herman and Roth 1984). Such environments have generally been used to overcome some of the problems of interrogating mental representations, and as such will be discussed below. However, the learning of such environments cannot be the same as learning a real-world environment because the size of the models and the room usually means that the whole display can be seen from one place, unlike the real-world which has to be built up from successive views (Acredolo 1981; Siegel 1981). Also, the framework of the room in which the model is placed may provide useful cues which aid memory (Acredolo 1981).

Aiv. Slides and videos

A number of experimenters have begun to present subjects with routes through environments in the form of series of slides (for example, Allen, Kirasic, Siegel and Herman 1979; Moar and Carleton 1982), video films (Thorndyke and Goldin 1983) or even computer simulated journeys (Clayton and Woodyard 1981). Such presentations have proved useful, particularly with adults, because they allow the subject to be presented with an environment without having to be taken there. However, there are still some problems. Such presentation means that the subject lacks locomotor experience with the environment. One always faces the screen, and information about the environment does not flow past as one moves along. The view provided by the slides or video is unidirectional; unlike walking a real route, subjects cannot turn their heads at choice points to see what the road that they have just walked down looks like in reverse. No investigators to my knowledge have directly compared spatial knowledge acquired from slide or video presentations, with knowledge of the same environment acquired naturally. In theory, slide or video presentation of environments should be useful for work with young children, as they overcome problems of physical fatigue whilst exploring the environment, and letting young children loose in areas where there is traffic or other such hazards. Cohen and Schnepfer (1980) and Allen (1981) have used slides to present an environment to seven year olds but to my knowledge no experimenters have presented environments in the form of slides or videos to children under seven years of age. This may be because it would prove difficult to persuade young children to sit still long enough to watch and attend to the presentation, or because the literature suggest that self-directed movement in an environment is particularly important in building up young children's spatial knowledge (for example, Feldman and Acredolo 1979; Poag, Cohen and Weatherford 1983).

Av. Large-scale environments

Several authors have presented young children with novel large-scale environments, and have controlled the quality and quantity of their experience with that environment (for example, Feldman and Acredolo 1979; Rowan and Hardwick 1983). Such methods overcome the problems encountered with the use of environments of different scales as mentioned above, but have other problems, such as finding a suitable existing environment, or having to construct such an environment (as in Hazen, Lockman and Pick 1978).

Avi. Conclusions

Small-scale environments, that is both table-top displays and walk-through models, are limited in their use and application to knowledge of the real world. Slide and video presentations differ from actual experience with an environment in many respects and may be unsuitable for use with young children. This thesis will therefore concentrate on large-scale environments as its aim is to investigate children's knowledge of the real world. Both natural acquisition, and experimenter controlled acquisition will be used to provide answers to different questions.

B. How the mental representation is interrogated.

Bi. Verbal protocol

Although asking a subject about a route or environment might be a useful way of enhancing data gained by other methods, it is generally agreed that verbal protocols underestimate children's spatial knowledge because young children lack the verbal skills necessary to express what they know (Neisser 1976; Herman and Siegel 1978; Spencer and Darvizeh 1981a), and because they pose the problem of taking input that is possibly simultaneous and transforming it into successive output (for example, Siegel 1981). Spencer and Darvizeh (1983) have found differences between Iranian and British three to five year olds' route descriptions, but not in their abilities to retrace routes, suggesting that description is culturally shaped, and does not reflect way-finding ability.

Bii. Sketch maps

Although subject-drawn sketch maps have been widely used to investigate spatial knowledge, particularly with adults (for example, Appleyard 1970; de Jonge 1962; Walsh, Krauss and Regnier 1981), and to some extent with children (for example, Biel and Torell 1977; Maurer and Baxter 1972; Rothwell 1976), their use particularly with children, has many problems which make the results difficult to interpret. The production of sketch maps is limited by the drawing abilities of the subjects (Byrne 1979; Evans 1980; Hardwick et al. 1976; Spencley 1977), which is particularly a problem for children. For example, Kosslyn, Heldmeyer and Locklear (1977) asked children to indicate what sort of drawings they thought best depicted an object's appearance, and then asked the children to draw the objects. They found that the children did not draw the kind of pictures which they thought best indicated the objects, and so cautioned against making inferences about internal representations from children's drawings. Young children may even be worse at displaying their spatial knowledge through drawing than they are at displaying them through verbal skills. Spencer and Darvizeh (1981b) found that three and four year olds' maps of routes were more 'primitive' than their verbal descriptions of the same routes, as analysis of what the children said while drawing their maps showed that they possessed knowledge which they either failed to include on the map, or displayed in such a way on the map as to be uninterpretable to anyone who did not have a transcript of what the child said. As well as limitations imposed by drawing skills, sketch maps are also problematical because 'intuitive knowledge of simple geometry allows one to deduce and construct facts which were not initially known: the task changes as well as taps the mental representation' (Byrne 1982, p. 242) so, for example, a cognitive map of an area may be many separate memories of different parts with poor integration, but these separate parts come to look more integrated when drawn on a flat two-dimensional surface (Moar 1979). If sketch maps are drawn by tracing along a linear path, any error will be cumulative, and so different starting points will produce differing end products (Byrne 1979). Some inaccuracies may reflect inadequacies of the paper size and shape (Catling 1978; Evans 1980). There is also the problem of how to interpret what has been drawn. Sketch maps may not be a true reflection of what the subject knows because they require 'translation' from the scale of the real world to the small-scale space of a piece of paper (Siegel 1981), selection of detail, and rotation from a horizontal to a vertical view (Spenceley 1977). Children's sketch maps may appear inaccurate because they have not yet learned the conventional ways of making such representations (Downs and Siegel 1981).

Biii. Model building

Two types of model building tasks have been used to investigate young children's spatial representations. Subjects have either had to construct table-top models of real-world sized environments, (for example, Piaget *et al.* 1960; Piché 1977; Siegel and Schadler 1977; Herman and Siegel 1978), or else they have reconstructed an environment which was learned as a walk-through model by placing identical items in a similar room (for example, Herman 1980; Herman, Kolker and Shaw 1982). There are problems with both these methods. The use of table-top modelling tasks may underestimate young children's spatial knowledge. For example, Spencer and Darvizeh (1981b) found that three and four year olds' abilities at making two- or three-dimensional models of an environment were much poorer than their performance in the real world. There are many reasons why small and large scale responses are not the same. Modelling tasks involve translation of scale, which can be problematical for young children if the task involves memory (Blades and Spencer, in press); small scale models preclude motor experience, and so the mode of response is different in terms of muscle patterns (Acredolo 1981; Evans 1980); small-scale models are viewed from a different plane than the real world (Evans 1980); small-scale spaces are located within the framework of the real world which may provide subjects with useful cues (Acredolo 1981); small-scale models can be viewed from one vantage point whereas this is often not true of real-world sized environments (Acredolo 1981; Siegel 1981).

Tasks in which children are required to reconstruct walk-through models overcome the problem of representation (that is, knowing that a model 'stands for' something in the real world), and the problem of translation of scale (Siegel 1981). However, the size and nature of the room in which the model is place must be clearly stated, as the results will be affected by whether cues can be obtained from objects around the edge of the room (Herman and Siegel 1978). There is also the problem that the size of the items chosen for the model villages, and the size of the rooms used, means that such models are not truly large-scale: the whole display can be viewed from one vantage point. There are pragmatic limitations with such a method in that it is difficult to obtain exclusive right to a large enough room or rooms for the duration of the experiment (Siegel 1981).

Biv. Route finding

Some authors have examined young children's abilities to retrace newly learned routes (for example, Spencer and Darvizeh 1981b; Rowan and Hardwick 1983; Spencer and Darvizeh 1983; Darvizeh and Spencer, in press). This method has provided some interesting findings about the route and landmark knowledge of preschoolers, for example, that there are cultural differences in route descriptions given by young children which are not reflected in their way-finding abilities (Spencer and Darvizeh 1983); and that landmark recall plays a critical role in preschool children's abilities to retrace newly learned route (Darvizeh and Spencer, in press). However, route finding alone is limited in the information it can provide, and unless it is combined with tasks which test children's ability to infer the spatial relations between locations along the route, it cannot provide a test of Euclidean or vector-map knowledge.

Bv. Distance estimations

Many researchers have investigated children's spatial knowledge using distance estimation tasks. The main methods used have been direct estimation of pairs of distances (for example, Biel 1982a; Newcombe and Liben 1982; Poag, Cohen and Weatherford 1983), rank ordering of distances (for example, Kosslyn, Pick and Fariello 1974; Allen et al. 1979; Newcome and Liben 1979; Siegel, Allen and Kirasic 1979), straight line reconstruction (for example, Cohen and Weatherford 1980; Cohen et al. 1980; Cohen and Cohen 1982), and free reconstruction (Cohen et al. 1979). Reconstruction tasks are only suitable for room-sized environments. Direct estimation of pairs of distances, and rank ordering of distances are more suitable for larger environments, but the fact that such tasks have not to my knowledge been used with subjects younger than six years of age may reflect the difficulty of making such a task comprehensible to preschool children. Also Da Silva (1983) has shown that children are significantly worse than adults at judging perceived distances. In Chapter 3 of this thesis, an attempt is made to find a distance estimation task suitable for preschool children.

Bvi. Direction estimates

Several authors have successfully used direction estimates to test the spatial knowledge of quite young children. For example, Hardwick et al. (1976) used a 'sighting tube' mounted on a tripod to test six, ten and twenty-one year olds' ability to manipulate their spatial knowledge of a familiar room; and Lockman and Pick (cited in Pick and Rieser 1982) used similar apparatus to test children as young as four years on their knowledge of the layout of their own apartment. Similar tests have also been used with older children (Piché 1979; Curtis, Siegel and Furlong 1981). Direction estimate are particularly appropriate for investigating young children's spatial knowledge because pointing is a skill learned early in life (see, for example, Wakaba 1981) and so the task is easily understood.

Siegel (1981) has suggested that the best method for externalizing spatial knowledge is to obtain from subjects both bearing and distance estimates to a number of landmarks from three different locations in a large-scale environment. However, preschool children have a short concentration span, and are easily bored with over-repetitive tasks. Taking both direction and distance estimates from one preschool child would either mean taxing that child beyond cooperation, or taking inadequate numbers of samples of both kinds of data.

Bvii. Conclusion

In conclusion, the most suitable task for the environments and preschool subjects chosen for this thesis would seem to be direction estimations. It is possible that many of the tasks which have been used in the past either underestimate the spatial skills of young children because of production difficulties, or are incomprehensible to them. Direction estimates are a suitable test of Piaget's topological and Euclidean spatial knowledge, and Byrne's (1979, 1982) network-map/vector-map theory of spatial representation. Piaget's theory (Piaget et al. 1960; Piaget and Inhelder 1967; Piaget 1977) predicts that preschool children should have topological route knowledge only, so they should be unable to make direct direction responses, and instead should point along the path to the target, as would also be predicted by the network-map hypothesis. Direct direction responses require the children to make an inference about unwalked directions to targets, and are therefore a test of Euclidean or vector-map knowledge. The accuracy of the bearings pointed reflects the accuracy of the children's Euclidean knowledge.

CHAPTER 3

An exploratory attempt to investigate the nature of preschool children's distance knowledge.

Introduction

Probably as a result of the methodological difficulties mentioned above, there is a distinct lack of research into preschool children's knowledge of distance. As described in detail in the introduction, for children of infant school age and above, some investigators have shown that children as young as six years can make accurate and consistent distance estimates in their home area (Biel 1982a) or in their school (Curtis et al. 1981 ~~in press~~), whilst other investigators have shown that in laboratory settings children rely heavily on functional distance, that is, distance along the route between locations, rather than actual crow-flight distance, when making distance estimations (Anooshian and Wilson 1977; Kosslyn et al. 1974). However, it has also been found that reliance on functional distance depends very much on the nature of the task set, with young children performing similarly to adults or older children where they do not have to hold the entire spatial layout in mind at one time (Newcombe and Liben 1982) or when they do not have to rescale or reorient their estimates (Cohen et al. 1979). The accuracy of young children's distance estimates can be increased by allowing them to direct their own movements when learning an environment (Poag et al. 1983), or by providing a theme which functionally relates the landmarks in an environment (Cohen and Cohen 1982).

The following investigation looked at three and four year olds' knowledge of distance in two separate environments of the same shape and number of locations but differing in scale. The aim was to make the task as simple as possible, so for each environment the children were merely asked to name the nearest and furthest object from a certain location. The small-scale experiment involved a 'table-top' sized display of objects which could be viewed from one vantage point. The large-scale experiment involved an environment large enough for the children to walk through, and which could not be viewed from one vantage point. The small-scale experiment required the child to make distance choices from a visual display, and so tested their understanding of the terms 'nearest' and 'furthest' without an added memory load. The large-scale experiment required that spatial knowledge was built up over a series of consecutive views, and held in memory.

General Method

Subjects

The subjects were twelve girls and twelve boys from Playgroups in St. Andrews, Fife, with ages ranging from 3 years 5 months to 4 years 10 months (mean 4 years 3 months). Six boys and six girls were randomly assigned to each experimental group: Group I received the small-scale distance test followed by the large-scale distance test, whilst Group II received the tests in the reverse order. All the children had previously taken part in one of the direction estimation tasks, and all had previously been tested on the English Picture Vocabulary (EPV) test (Brimer and Dunn 1973), a test of comprehension of spoken words. Their mean EPV score was 111.7, with a standard deviation of 11.6.

I Small-Scale Distance Experiment

Method

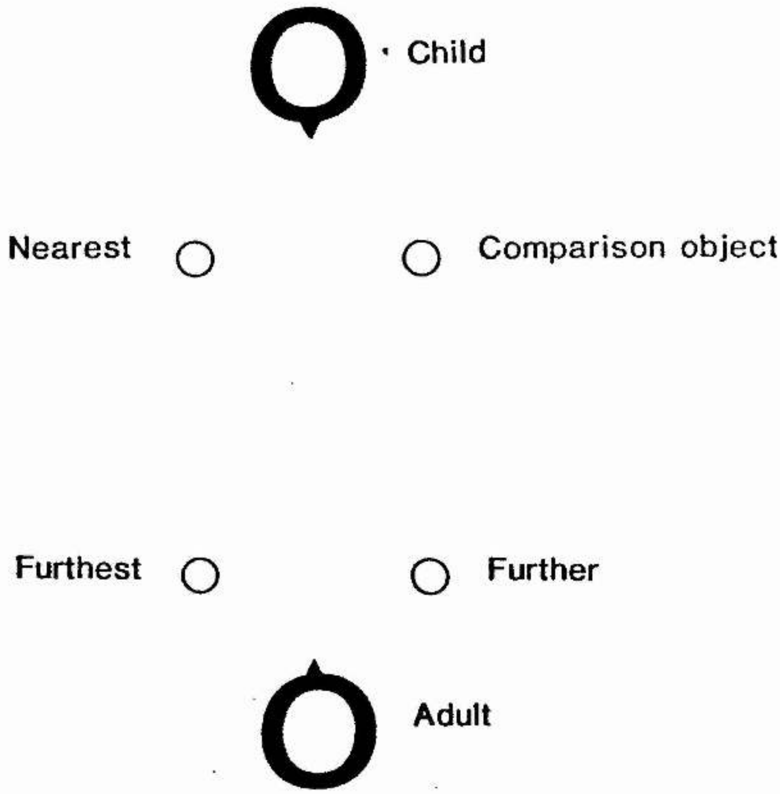
Apparatus

Four pocket-size plastic toys - car, fence, horse, and elephant.

Procedure

The children were tested individually. The four toys were shown to the children who were asked to name them. The names given by the children were used throughout the test. The children watched whilst the experimenter placed each toy in front of them so that they formed a 6 inch by 9 inch rectangle with one toy at each corner. Each toy was always placed in the same location. The children were told to look very carefully where each toy was so that they would be able to answer some questions about them. The children were then asked to name or point to the animal which was nearest to/furthest from a certain other toy. By the end of the test the toy nearest to and furthest from each of the other toys had been asked for (Fig. 2). The order of testing was randomized. Each child was rewarded with a small sweet, regardless of performance.

Fig. 2 Nearest, further, and furthest responses.



Results

The children's responses were categorized into 'near', 'further', and 'furthest' responses, as illustrated by Fig. 2, for each type of question. It could be argued that the nature of the children's responses is affected by whether they were tested on this small-scale distance experiment before the large-scale distance experiment or after it. However, Chi square tests on both the 'nearest' and 'furthest' questions show that the order of testing did not significantly effect the distribution of responses (Nearest: $X^2 = 1.182$, 2df; Furthest: $X^2 = 3.216$, 2df). The results were therefore combined across order of testing in all further analysis. Table 2 shows the distribution of responses with order of testing.

It was hypothesized that the children's responses may be affected by whether the comparison object was close to the child or not. Table 3 shows the distribution of responses according to the closeness of the child to the comparison object. Chi square tests showed that the distance of the child from the comparison object did not significantly effect the distribution of responses (Near question $X^2 = 1.03$, 2df: Furthest question: $X^2 = 0.73$, 2df), therefore the results were combined for all further analysis. The combined results can be seen in Table 4. Chi square tests were carried out to see whether the sex of the subjects affected their responses. For both 'nearest' and 'furthest' questions, the distribution of responses was not significantly different for boys and girls (Nearest: $X^2 = 1.613$, 2df; Furthest: $X^2 = 4.764$, 2df). Table 5 shows the distribution of responses according to the sex of the subjects.

Table 2   The distribution of responses with order of testing

	Number of responses					
	Tested first			Tested second		
	Near	Further	Furthest	Near	Further	Furthest
Nearest Question	37	8	3	40	7	1
Furthest Question	5	22	21	1	21	26

Table 3 Distribution of responses according to the distance of the child from the comparison object.

	Comparison object is					
	Near to child Response item is			Far from child Response item is		
	Near	Further	Furthest	Near	Further	Furthest
"Nearest" Question	38	7	3	39	8	1
"Furthest" Question	3	23	22	5	20	23

Table 4 Combined Results

	Item chosen is		
	Near	Further	Farthest
Nearest question	77	15	4
Furthest question	8	43	45

Table 5 The distribution of responses according to the sex of the subject.

	Number of responses					
	Girls			Boys		
	Near	Further	Furthest	Near	Further	Furthest
Nearest Question	38	9	1	39	6	3
Furthest Question	2	21	25	8	22	18

The results were collapsed across sex in all further analysis. Were the children equally likely to be correct on each question? A binomial test showed that significantly more correct responses were given to the 'nearest' question than incorrect responses ($Z = -14.69$, $p < .001$). However, the responses to the 'furthest' question, showed that there was no significant difference between 'further' and 'furthest' responses (Binomial test: $Z = -0.294$), but significantly less near responses than other responses (binomial test: $Z = -30.03$, $p < .001$). There are three possible hypotheses for the responses to the 'furthest' question, which are shown with their expected distribution of responses in Table 6. Chi square tests showed that the actual distribution of responses was significantly different from the expected distribution for hypotheses 1 and 3 (1: $X^2 = 57.91$, 2df, $p < .01$; 3: $X^2 = 325.98$, 2df, $p < .01$), whereas the actual distribution of responses was not significantly different from the expected distribution for hypothesis 2 ($X^2 = 2.29$, 2df). That is, the children made no distinction between 'further' and 'furthest'.

For the 'nearest' question there is no significant correlation between the number of correct responses given and age in months or scores on the English Picture Vocabulary Test. For the 'furthest' questions, there was no significant correlation between either the number of 'furthest' responses or the number of 'further' responses, and the age in months or scores on the English Picture Vocabulary Test.

Discussion

Table 6 Hypotheses for possible responses to the 'furthest' question

Hypothesis	Predicted pattern of response		
	Near	Further	Furthest
1. Random responding	32	32	32
2. Can't distinguish 'further' from 'furthest'	5*	46	46
3. Can tell 'furthest'	5*	5*	86

* chance level of responding (p = .05)

The results suggest that the children were able to distinguish between 'nearest' and 'furthest', but they cannot distinguish between 'further' and 'furthest'. This could be for two reasons: either the children cannot distinguish linguistically between further and furthest, or else they cannot distinguish spatially between further and furthest in this particular situation. There is apparently a stage in the acquisition of terms of comparison when children make no distinction between comparatives and superlatives (Wales and Campbell 1970); they may therefore be giving the 'further' answer to the 'furthest' question.

Large-Scale Distance Experiment

Method

Apparatus

1. Four large flowerpots - in which the toys were hidden.

2. Four toys - crow and monkey glove puppets, plastic spoon, and coloured pencil.

Procedure

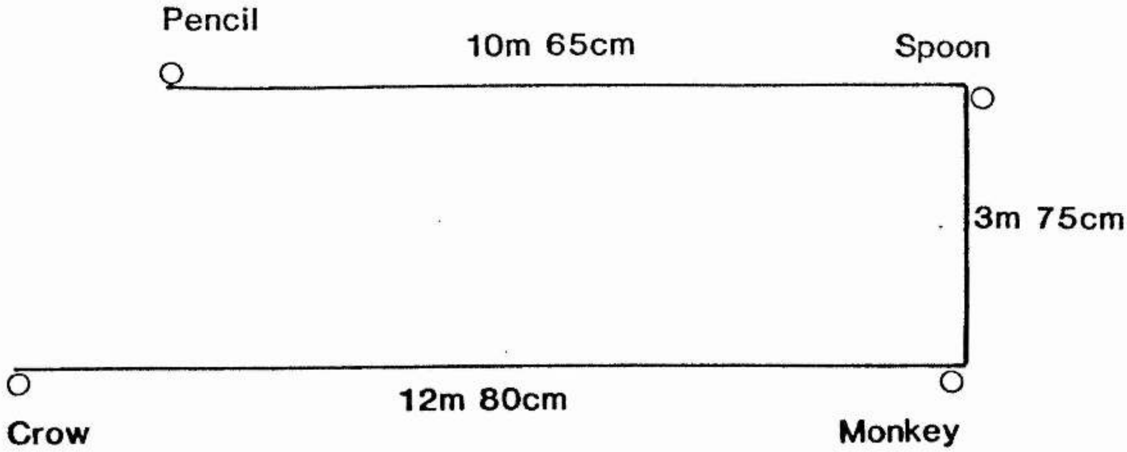
Learning Phase

Each child was shown the four toys and asked to name them. The names given by the child were used throughout the experiment. The children were told that they were going to play a kind of hide-and-seek game, in which they had to help the experimenter hide the four toys in the four large flowerpots. They were asked to remember where the toys were hidden because the experimenter had a very bad memory and would not be able to find them or her own, and so that they would be able to answer some questions. The toys were hidden in their flowerpot at the corners of an almost rectangular set of corridors as shown in Fig. 3. In order to maximise the children's chances of learning the layout of the environment, they hid the toys themselves (although the experimenter indicated where to hide them), and explored the experimental environment by themselves (Herman and Siegel 1978; Feldman and Acredolo 1979). The toys were hidden in the same locations for each child. The children explored the environment for two minutes, and were encouraged to remember the location of each toy.

Test Phase

The experimenter and child visited each location in turn. At each location the child was told 'I want you to pretend that you are a ghost or superman/wonderwoman who can walk through walls so that you can get to the hidden toys by any way you want instead of just by going along the paths we have just walked. Or you can pretend that all of the walls have become 'see-through' like windows so you can see all the hidden toys. If that were true, which toy would be nearest to/furthest from the ......? Would it be the ......, the ...., or the .... (naming the 3 other toys)?' The order of the nearest/furthest questions was randomly alternated. The child

Fig. 3 Experimental area for large-scale distance test.



responded by naming one of the toys, and the name of the toy was recorded.

Results

For both the nearest and the furthest question, the position of the location from which the child pointed determined the range of potential answers available. From Fig. 3 it can be seen that questions asked from the crow or pencil require vector-map knowledge for a correct answer, and other responses are either 'correct' according to network-map knowledge, or wrong. These questions will be called Type 1 questions. From the monkey and the spoon, the correct answer can be given using either network-map knowledge or vector-map knowledge, and the two cannot be distinguished, or else the response is wrong. These will be called Type 2 questions. The children's responses were categorized according to question type and response type. Chi square tests showed that for both nearest and furthest questions, the distribution of responses to Type 1 questions and Type 2 questions was not significantly affected by the order of testing, except the responses to the nearest Type 1 question, where there was a just significant difference in the distribution of response types. (Nearest Type 1: $X^2 = 6.92$, 2df, $p < .05$; Furthest Type 1: $X^2 = 5.72$, 2df; Nearest Type 2: $X^2 = 0$, 1df; Furthest type 2: $X^2 = .91$, 1df). (See Table 7) The results were collapsed over order of testing for the rest of the analysis. Chi square tests showed that for both nearest and furthest questions, and for both question types, there were no significant differences in the distribution of responses between the boys and the girls (Nearest 1: $X^2 =$

Table 7 Distribution of responses according to order of testing

Question	Order of testing	Response type		
		Vector-map	Network-map	Wrong
Type 1 Nearest	1st	1	23	0
	2nd	5	16	3
Type 1 Furthest	1st	10	14	0
	2nd	9	10	5
Type 2 Nearest	1st	15		9
	2nd	15		9
Type 2 Furthest	1st	12		12
	2nd	9		15

.966, 2df; Furthest 1: $X^2 = 1.48$, 2df; Nearest 2: $X^2 = 3.29$, 1df; Furthest 2: $X^2 = .17$, 1df), (see Table 8).

For Type 1 and Type 2 questions, the distribution of responses to nearest and furthest questions were compared using Chi square tests, and it was found that for both question types the distribution of responses to nearest questions was significantly different from the distribution of responses to furthest questions (Type 1: $X^2 = 45.87$, 2df, $p < .001$; Type 2: $X^2 = 6.83$, 1df, $p < .01$). The results will therefore be examined separately. Table 9 shows the distribution of responses to each question type. The distribution of responses in each condition was compared to the distribution expected by chance, using Chi square tests. For the nearest questions, the responses to type 1 and type 2 questions were significantly different from chance (Type 1: $X^2 = 45.87$, 2df, $p < .001$; Type 2: $X^2 = 15.45$, 1df, $p < .001$). In the case of the type 1 question, only th network-map responses were above chance level, and in the case of the type 2 questions, the vector-map/network-map responses were above chance level (Table 9). So it seems that the children are not answering the nearest question randomly, but are relying upon network-map knowledge. For the furthest questions, the responses to the type 1 questions differed significantly from chance ($X^2 = 16.18$, 2df, $p < .01$), with the number of network-map responses being well above chance level; but the response to the type 2 questions did not differ significantly from chance ($X^2 = 1.01$, 1df). The children therefore seem to respond to the furthest question randomly, or by using network-map knowledge.

Table 8 Distribution of responses according to sex

Question	Sex	Response type		
		Vector-map	Network-map	Wrong
Type 1 Nearest	F	2	20	2
	M	4	19	1
Type 1 Furthest	F	11	10	3
	M	8	14	2
Type 2 Nearest	F	18		6
	M	12		12
Type 2 Furthest	F	11		13
	M	10		14

Table 9 The distribution of the children's responses.

Question		Response type		
		Vector-map	Network-map	Wrong
Type 1	Nearest	~~1~~6	~~38~~ 39	3
	Furthest	19	~~25~~ 24	~~3~~ 5
	Chance level	16	16	16
Type 2	Nearest	~~29~~ 30		~~19~~ 18
	Furthest	~~20~~ 21		~~28~~ 27
	Chance level	16		32

There was a just significant correlation between vector-map responses and age to type 1 nearest questions ($r = .49$, 22df, $p < .05$), but there were no other significant correlations between network-map and/or vector-map responses and either age or EPV scores.

Discussion

The results suggest that the children used string-map or network-map knowledge to answer the 'nearest' question; whilst to the furthest question they responded randomly, suggesting that they have no spatial knowledge with which to answer the question, or are using string-map or network-map knowledge. Why the difference between the two questions? Firstly, the nearest question is easier than the furthest question, because, if one relies on network-map knowledge, as the children apparently do, the nearest object according to the walked route is almost in view (the child can at least see the topological cue of the corner around which the object is hiding), but to answer the furthest question no such topological cues are available. Secondly, the network-map hypothesis predicts that distance would be calculated according to the number of nodes or locations between objects (Byrne 1982), producing a functional or walked distance response, consistent with the findings for infant - school aged children (Anooshian and Wilson 1977; Kosslyn *et al*. 1974). However, the previous experiment showed that preschool children cannot distinguish between further and furthest. They are therefore probably using network-map knowledge to answer the 'furthest' question in the present experiment, but their inability to distinguish between further and furthest led to apparent randomness in their estimation of the appropriate number of nodes between them and the target object to constitute the correct answer.

General discussion of small-scale and large-scale distance experiments

On the whole, in neither experiment were the children's patterns of responses affected by the order in which they performed the two experiments, even though one might expect that having seen the whole layout of four objects previously would improve the children's abilities on the large-scale experiment. For the nearest questions, the children tended to respond correctly on the small-scale experiment, but to rely on network-map knowledge on the large-scale experiment. This finding is consistent with Acredolo (1977) who found that three, four and five year old children performed more accurately on a table-top spatial task than on a similar room-sized spatial task, even though her room-sized task was not truly large-scale as the whole room could be viewed from one vantage point. In the small-scale experiment, the 'furthest' question produced a mixture of 'further' and 'furthest' responses, suggesting that preschool children are unable to make the fine spatial distinction between 'further' and 'furthest' even when the whole display is in view, or that they cannot make the linguistic distinction between 'further' and 'furthest'. In the large-scale experiment, the children either responded randomly to the 'furthest' question or used network-map knowledge. The apparent randomness could have been the result of network-map knowledge plus their inability to distinguish between further and furthest. The results of both experiments caution against the use of distance tests with preschool children, especially because their linguistic miscomprehension may lead to an underestimation of their spatial knowledge. Because of the difficulty of finding a distance estimation task which is suitable for young children, and which does not rely on understanding comparatives and superlatives, I will concentrate on direction estimations in this thesis to investigate preschool children's spatial knowledge.

CHAPTER 4

To investigate the use of direction estimates when exploring preschool children's spatial knowledge

Introduction

The following pilot tests provide an initial exploration of the feasibility of using direction estimates to study preschool children's spatial knowledge; and also begin to look at some of the factors which affect their knowledge of direction. Indoor environments were chosen in the hope that this would speed up the testing: as the test areas were near to the Playgroup, it was hoped that the children would be more likely to go with the relatively unfamiliar Experimenter, than they would have been to leave the building with her. It was also hoped that it would be easier to manipulate indoor environments to the required shape or size than it would be to find natural environments of the necessary dimensions. The tests fall into two sections: those which explore the effects of different kinds of barriers on the children's directional estimates; and those which look at the effect of an unwalked path between targets on the children's directional estimates.

General Procedure

The subjects were all members of the Puffin Playgroup, St. Andrews, Fife, and were accustomed to the Experimenter playing with them in the Playgroup. Directional estimates were taken by the children pointing with their own fingers, and the Experimenter recorded the object or path to which they pointed. With the exception of the test using walls as barriers, the tests were all carried out in a large room, in which the required apparatus was arranged. However, because of the short availability of the room and apparatus, and the difficulty of moving the screens used, only one day could be allocated to each test, and the order of testing could not be counterbalanced across the children. This unfortunately meant that due to illness or lack of cooperation on the appropriate day, not all children took part in every test. However, for each test, the number of previous tests performed by each child was correlated with the number of correct responses given by that child. None of the correlations were found to be significant, so previous experience was not considered in the rest of the analysis. All children had previously been tested by the Experimenter on the English Picture Vocabulary Test (EPV) (Brimer and Dunn 1973), a measure of comprehension of spoken words. Each child was tested individually.

Group I: The effect of different barriers on directional estimates

Method

Subjects: a summary of the subjects who took part in each experiment is given in Table 10.

Apparatus:

Table 10 Details of subjects

	No barriers	Chair barriers	Screen barriers	Wall barriers
No. of Boys	9	8	12	10
No. of Girls	11	7	11	14
Total subjects	20	15	23	24
Mean age	3:7	3:8	3:11	4:1
Age range	2:9 to 4:5	2:9 to 4:5	3:1 to 5:0	3:2 to 5:1

4 large flowerpots

16 small toys, for example, farm animals

Chairs

Screens, approximately 4 foot high, by 6 foot wide, by 1 inch thick.

Procedure

Four chairs were placed as shown in Fig. 4. A large flowerpot with a toy hidden inside was placed on each chair. In the positions indicated in the diagram, were placed either no barriers at all, or barriers made of chairs (barriers to movement only), or barriers made of screens (barriers to movement and vision), or, in the case of the wall barriers test, the test was conducted around a rectangle of internal walls as shown in Fig. 5. Each child walked around the outside of the area with the Experimenter, and explained and named each toy in turn. The names given for the toys by each child were used during the test. The children were told that they had to remember where each toy was, and were allowed to walk round the square examining the toys until they were satisfied that they knew this. Different toys were used in each test. From the positions indicated in Figs. 4 and 5, each child was asked to point to each of the toys in turn by the Experimenter asking, "Where is the ____? Can you point to the _____?" The children were encouraged to point the crow-flight direction to the target by the Experimenter asking them to pretend that all the barriers or walls had become 'see-through' like windows so that they could see the target and point to it; or that they were superman/wonderwoman/a ghost who could walk through walls, and to point the way they would walk to the target. The

Fig. 4 Layout of the area used for Group 1 tests.

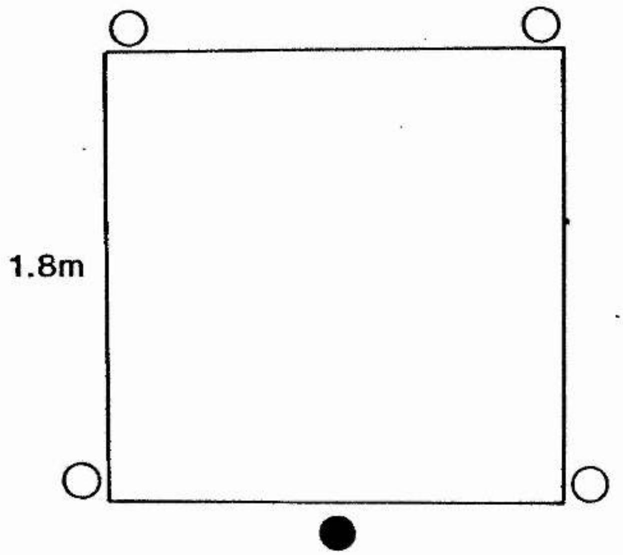
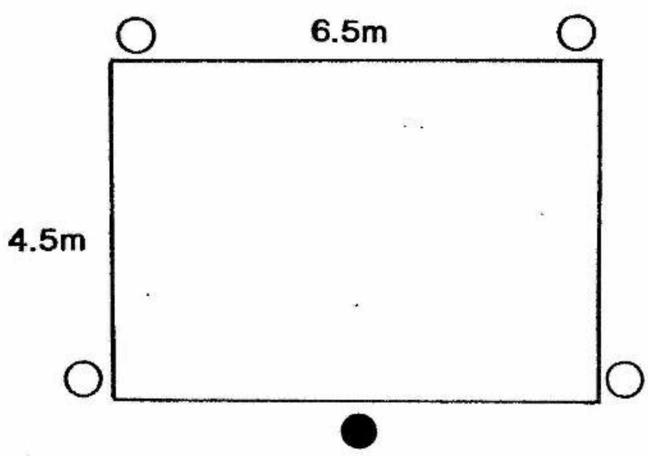


Fig. 5 Area used for the wall barrier test.



○ toy hidden in a flowerpot

● test place

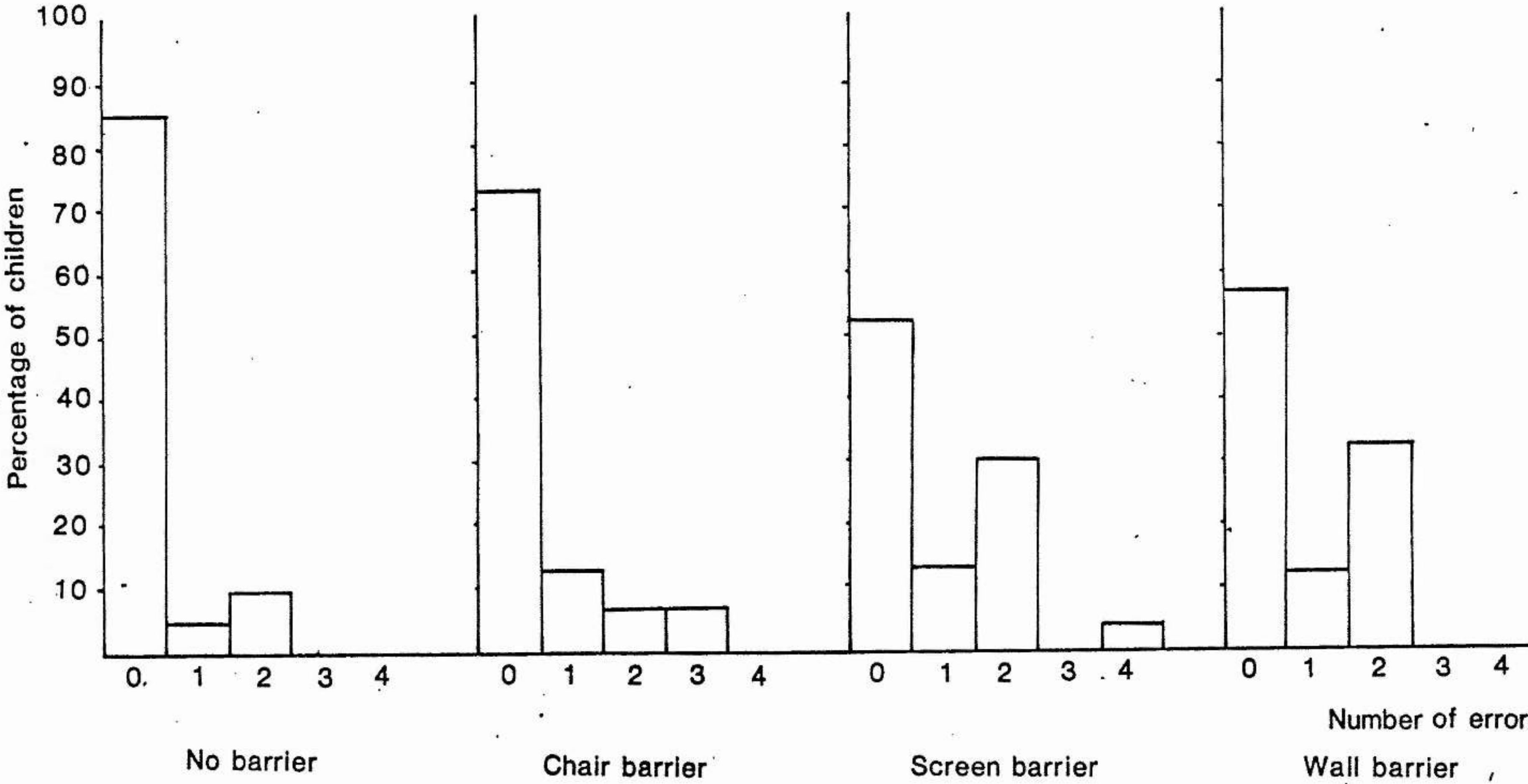
— barrier, wall, or in one condition this was removed child's response was recorded. Each child was rewarded with a small sweet, which was not contingent upon the quality of his or her performance.

Results

The children's responses were categorized as errors when they did not point through the barriers to the target. Fig. 6 shows the percentage of children in each test who made 0, 1, 2, 3 or 4 errors. Chi square tests show that on the screen barrier test and the wall barrier test significantly more children made errors than when there was no barrier present (Screen: $X^2 = 18.12$, $p < .001$; Wall: $X^2 = 16.49$, $p < .001$). This was not so for the chair barrier test. Fig. 6 shows that on all tests, many children made two errors, but few made more errors than this. This was probably because in each case pointing the crow-flight direction to two of the targets was indistinguishable from giving a response derived from network-map knowledge. When all the results were combined, there were no significant correlations between either age nor scores on the EPV and the number of errors made by each child. On the wall barrier test, the children's comments were recorded when they were unable to point through the walls to the target. In these cases, the children pointed along the way we had walked to the target, and made such comments as 'that way, then that way', 'round the way we went', 'round the corner', or 'round there'.

Conclusions

Fig. 6 Percentage of children making 0,1,2,3,4 errors.



The results suggest that only barriers to vision as well as movement (screens and walls) significantly effect the proportion of children who make errors; whereas barriers to movement only (chairs) did not produce results significantly different from no barriers. The errors in the case of barriers to vision and movement were that the children pointed along the path to the target, instead of through the barriers, that is, they gave a response consistent with network-map knowledge. The children's verbal responses indicate string-map or network-map knowledge of the target's location.

Group II: the effect of an unwalked path between targets on the children's directional estimates

Method

Subjects: a summary of the subjects who took part in each test is given in Table 11.

Apparatus:

4 large flowerpots

Small toys

Chairs

Screens, approximately 4 foot high, by 6 foot or 4 foot wide, by 1 inch thick.

Procedure

Four chairs were placed as shown in Fig. 7. A large flowerpot

Table 11 Details of subjects

	Chairs	Screens	Broken Screens
Number of boys	6	9	12
Number of girls	9	9	8
Total subjects	15	18	20
Mean age	3:8	3:11	3:11
Age range	2:11 to 4:7	3:1 to 5:0	3:1 to 5:0
Mean EPV	117.7	115.7	114.6
EPV SD	10.0	11.4	12.1

Fig. 7 Location of chair barriers or screen barriers.

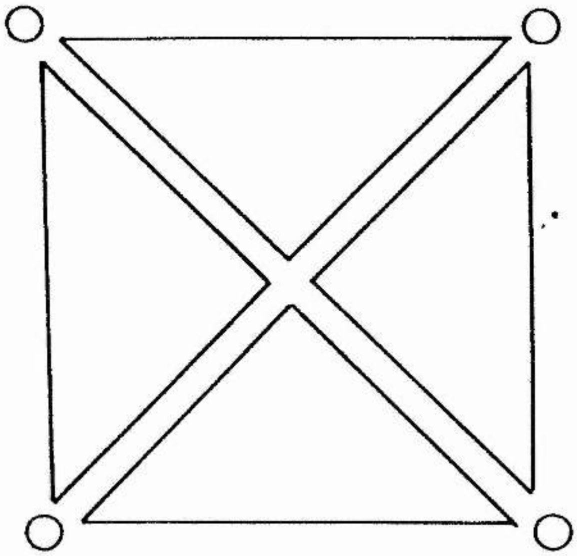
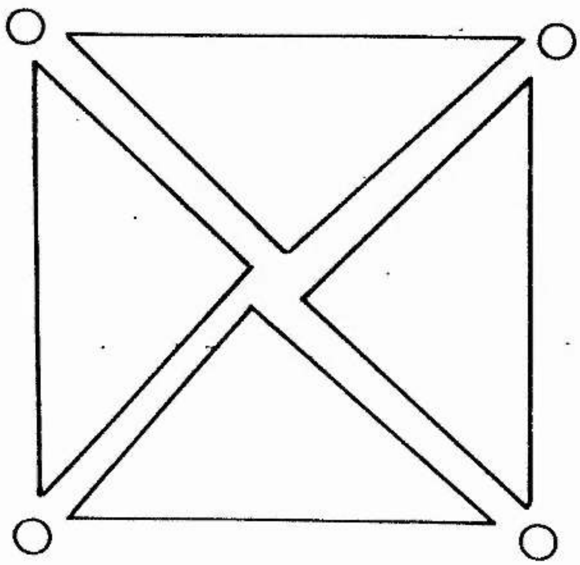


Fig. 8 Location of misaligned screen barriers.



○ target object placed on a chair

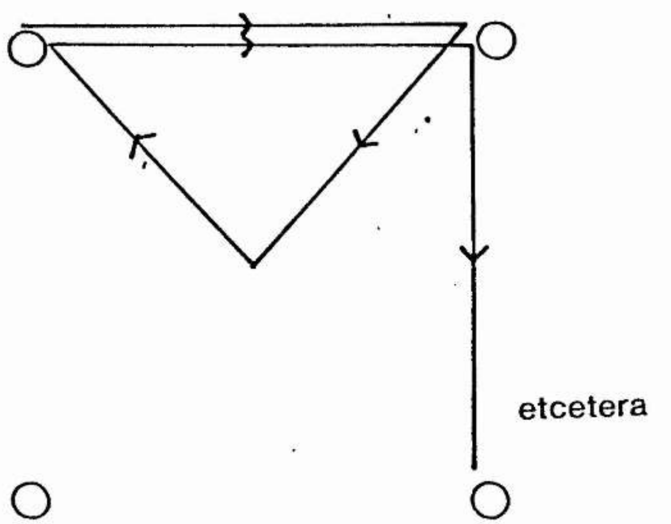
— chair or screen barrier

with a toy inside was placed on each chair. In the positions indicated in Figs. 7 and 8, were placed barriers of chairs (barriers to movement only), or screens (barriers to movement and vision). In the second screen test, the screens were so placed that the target objects could not be seen when the subject looked along the diagonal path (Fig. 8). Each child learned the experimental area by following the experimenter on a route such that they never walked the whole length of the diagonal pathway at one time, as shown in Fig 9. As each flowerpot was encountered, the child examined and named the toy hidden inside; the name given by the child was used throughout the test. The children were asked to try and remember where each toy was. When the task was completed, the child was taken to each target in turn and asked to point to two other targets, one of which was the diagonally opposite target. The order of pointing to these two objects was randomized, as was the choice of the nondiagonal target for pointing. The children's responses were recorded in terms of the object to which they pointed. They were all rewarded with a small sweet, however they had responded.

Results

The children's responses were categorized as errors when they did not point through the barriers to the correct target. Responses to diagonally opposite targets were analyzed separately from responses which lay along the walked route. Fig. 10 shows the percentage of children making 0, 1, 2, 3 or 4 errors on each test. To ascertain the effect of barrier type and route type on the children's responses, an analysis of variance (subjects x route type

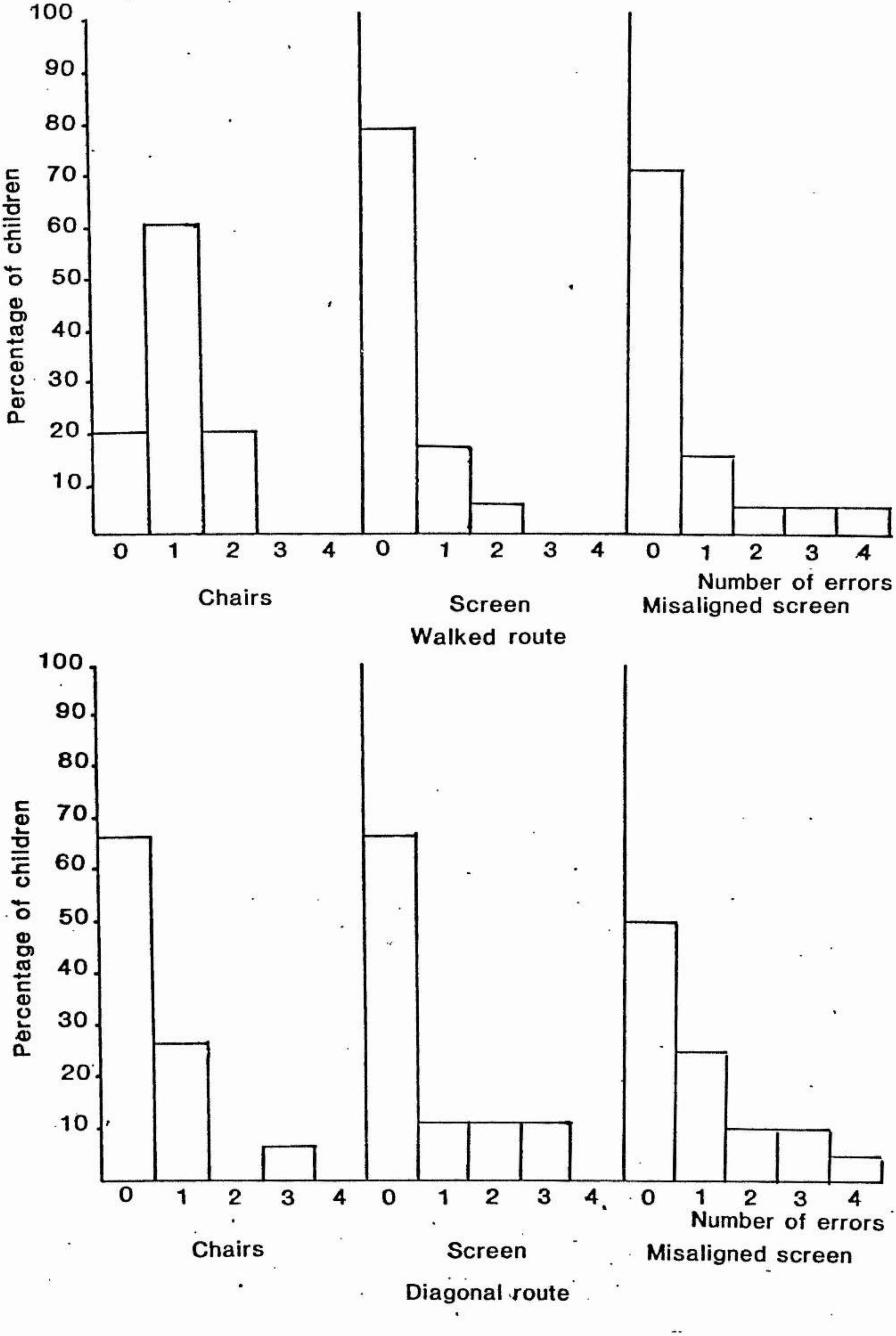
Fig. 9 Route taken by each child.



○ target object placed on a chair

→ route travelled

Fig. 10 Percentage of children making 0,1,2,3,4 errors



x barrier type) was carried out on the proportion of correct responses made in each condition, with missing data substituted by the mean for that condition. There were no significant main effects, but a significant interaction between route type and barrier type ($F = 9.98$, 46 df, $p < .001$). Table 12 shows the means and standard deviations for each condition. Tukey's HSD tests showed that significantly more correct responses were made for the walked route with screen barriers than for the diagonal route with either screen barriers (HSD = 13.09, 46 df, $p < .05$) or misaligned screen barriers (HSD = 15.81, 46 df, $p < .05$). When all the results were combined, there was a significant negative correlation between age and the number of errors made ($r = -.44$, 51 df, $p < .01$); that is, older children made less errors. There was no significant correlation between errors and scores on the EPV test.

Conclusion

The results show that in the simple layout employed here, it is not necessary for preschool children to have walked an entire path from one target to another in order to point along that path to the target. However, there is a slight indication that barriers to movement only lead to more correct responses than barriers to sight and vision for the walked route; and that barriers to sight and vision are more likely to reduce the proportion of correct responses to targets that lie along paths which have not been walked in their entirety, than along walked paths. Nevertheless, the children appear to have more than string-map knowledge of the walked route: their knowledge of the four sections of the diagonal paths, experi-

Table 12 Means and standard deviations for each route type and barrier type

	Walked route			Diagonal route		
	Chair	Screen	Misaligned screen	Chair	Screen	Misaligned screen
$\bar{x}$	73.2	93.0	85.0	86.1	79.9	76.9
SD	13.7	14.4	26.0	17.8	24.0	28.1

enced at different times, have been joined to form a network-map representation.

As there are no overall significant differences between the proportion of errors made for the diagonal and nondiagonal targets, the decreasing number of errors made with increased age is probably due to an increased ability to remember the positions of four targets per se, and not to an increased ability to point to targets down unwalked paths.

General Discussion for Group I and Group II tests

When there are barriers to sight and movement the preschool children tested here a) point through the barriers to the target, or b) point along a path one could walk to the target. Pointing through the barrier suggests that the children have Euclidean or vector-map knowledge, although the exactness of their pointing is not known because the bearing of their response was not measured for comparison with the bearing to the target. Such knowledge would not be predicted for preschool children by any of the current theories of development of spatial knowledge (for example, Piaget *et al.* 1960; Piaget and Inhelder 1967; Piaget 1977; Siegel and White 1975). The responses in which the children point along the path suggest that the children have string-map or network-map knowledge (Byrne 1979, 1982) and are similar to the findings of Piché (1977) in which five to eight year old children pointed to a target location in a network of streets by indicating the path they had just walked along. These responses are not inconsistent with current theories of preschool children's spatial knowledge as being route-like and topological (Piaget et al. 1960; Piaget and Inhelder 1967; Piaget 1977; Siegel and White 1975). The results of the Group II tests show that the children's knowledge is network-map knowledge rather than string-map knowledge, as different parts of a path experienced at different times have been joined in the children's representations to form a network. But why, given this network of paths, should the children choose to point along the most direct path to the target? This is probably because the diagonal path does not pass any other toys before the target location, whereas the nondiagonal path would pass one other location before the target location. So, using a topological code in which distance is equal to the number of 'nodes' passed, the diagonal path would be the shortest route.

Nevertheless, the experimental space used in the above tests was very small compared to the type of situations encountered in everyday life. The children may also have used the 'container' of the room in which the experiments were conducted to aid orientation (compare Herman and Siegel 1978). The results found here may not be applicable, therefore, to real-life situations. Since it also was not found to be easy to test the children in such an artificial situation, for practical reasons such as the availability of the room and equipment for testing, it therefore seems appropriate to try and test the children in more natural situations. The extra time and effort spent in building up the trust and friendship of the children before this can be done will be rewarded by the additional validity of the results, both in terms of maximising the children's level of responding, and in terms of the appropriateness of the environment chosen.

CHAPTER 5

To investigate the use of direction estimates as a measurement of preschool children's spatial knowledge in a real-world environment.

Introduction

In the past few years there has been a move towards looking at children's spatial knowledge and behaviour in naturalisitic settings, that is, in environments which they normally encounter in their everyday lives, rather than using laboratory based experiments (for example, Cohen, Baldwin and Sherman 1978; Spencer and Darvizeh 1981a, 1981b, 1983; Biel and Torell 1982). While laboratory based experiments are necessary for certain investigations, there are many advantages in using "real-world" environments. For the reasons explained in the introduction to this thesis, the size of many laboratory environments makes it difficult to extrapolate the findings to children's behaviour in the real world. It is, of course, more difficult to test young children in the real world, especially if this is an outdoor setting, as the Experimenter will need to have gained the trust and confidence of the children and their parents to a greater extent than if the children are merely brought to and tested in a laboratory. The Experimenter also needs not only to gain the children's cooperation with the experimental task, but also to protect them from the everyday dangers encountered outside a laboratory, such as traffic. Nevertheless, the extended amount of time needed to build up friendship with each of the subjects can only be beneficial in the long run, as it will enhance the children's cooperation and so maximise their chances of responding to the best of their ability. The following pilot study investigates whether direction estimates can be used to look at preschool children's knowledge of a real-world environment. The environment consisted of a simple, rectangular pattern of streets. The children made direction estimates by pointing to an out-of-sight target, and a compass bearing was taken of the child's response.

Method

Sample

The subjects were five girls and five boys who were member of the Puffin Playgroup, St. Andrews, Fife. Their ages ranged from three years five months to four years nine months, with a mean age of four years three months. Before testing began, the Experimenter played with the children in the Playgroup for some weeks so the subjects felt at ease with her. Each child had also taken part in the experiments described in Chapter Four and had previously been tested on the English Picture Vocabulary test (EPV) (Brimer and Lloyd, 1973) a measure of comprehension of the spoken word. Their mean EPV score was 117.7, with a standard deviation of 11.16.

Materials

1. Large wooden arrow - used by the children to point to out-of-sight targets.

2. Silva compass - used to measure the bearings pointed by the subjects.

3. Ordnance survey map of the experimental area, scale 1:2500 - used to discover the accuracy of the subject's responses.

Procedure

All the subjects were taught individually to point with the wooden arrow and to hold it very still whilst the Experimenter laid the compass on top of the arrow to read the bearing they pointed to (Figs. 11 and 12).

Each child walked individually with the experimenter over the chosen route three times on different days (three trials). The route was along streets which formed three sides of a rectangle (Fig 13) and with a distinctive archway at the beginning of the route. The archway was pointed out to each child, and the children were asked what they would call it. The name they gave was used throughout the experiment. At the archway, the children were told that they were going on a short walk with the experimenter, and that on the way they would stop at five places at which they would be asked to point to the archway with the arrow. The children were then led on the route and at each test location they were asked to point to the archway using the arrow. If they had difficulty, they were encouraged to point to the archway by pretending that everything between them and the archway had become 'see-through' like windows so that they could see the archway and point to it; or that

Fig. 11 Pointing with the wooden arrow

Fig. 12 Measuring the bearing with a compass

they were superman/wonder woman/a ghost who could walk through walls, and to point the way they would walk to the arch. The bearing of the child's pointing to the archway was measured from each of the five chosen locations (Fig. 13).

Results

The bearings pointed by the children were corrected for magnetic variation, and then compared with the 'true' grid bearing as measured from the Ordnance Survey map.

The difference between each child-given bearing and the true bearing for each location was calculated, producing error scores. The direction of the error, clockwise or anti-clockwise from the true bearing, was not taken into account. An analysis of variance on the children's errors from the true bearing (subject x location x trial x sex) gave a significant effect of trial ($F = 5.89$, 16 df, $p < .02$) and of location ($F = 6.11$, 32 df, $p < .001$). Table 13 shows the means and standard deviations of errors on each trial. Tukey's HSD tests showed that the children made significantly greater errors on trial I than trials II and III ($HSD = 13.72$, $p < .05$); and significantly smaller errors from location A than from any other location except C ($HSD = 32.43$, $p < .05$), which is to be expected as the correct response from A is the point along the path. No other comparisons were significant. There was no correlation between the size of the children's average errors and age, or scores on the EPV test.

Fig. 14 shows the distribution of responses for each location (all 3 trials combined). The same experimental area was used with

Fig. 13 . The Experimental Environment

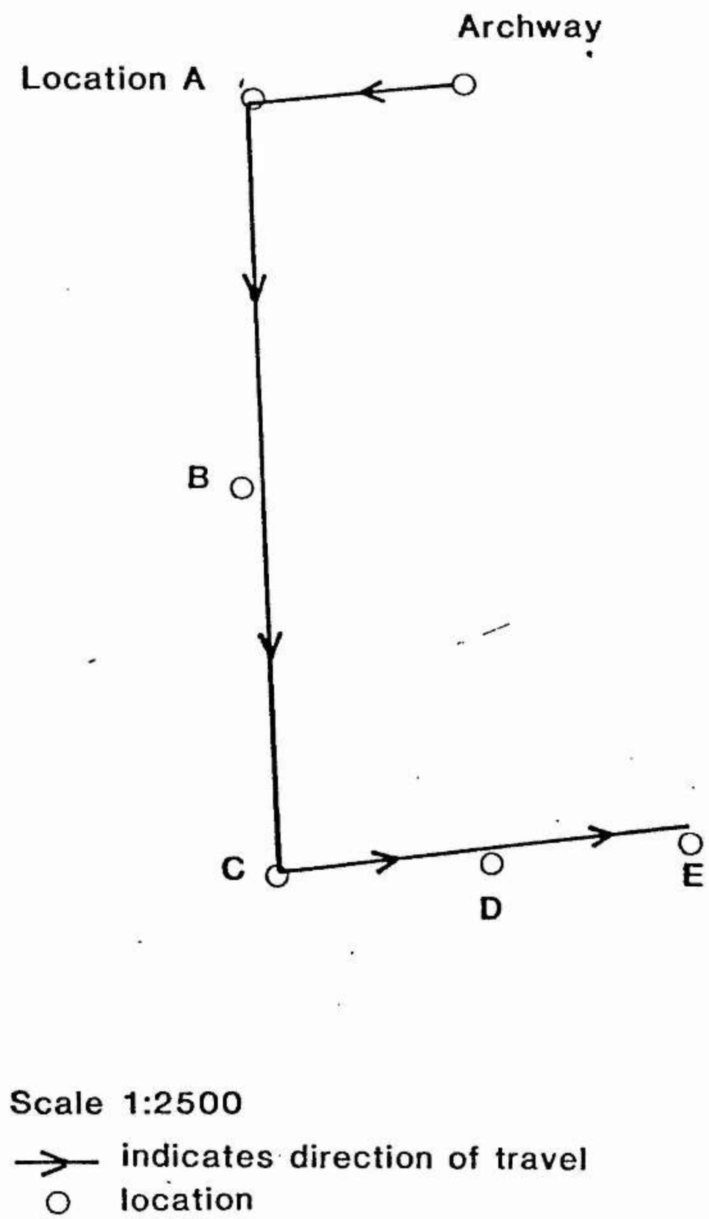


Table 13 Means and standard deviations for error scores on each trial

	Trial I					Trial II					Trial III					
	Location A	B	C	D	E	Location A	B	C	D	E	Location A	B	C	D	E	Total
Mean	32.2	72.1	60.9	74.6	73.2	7.0	60.2	50.3	54.5	70.4	20.6	71.6	45.2	30.8	59.4	52.23
Standard deviation	37.6	66.1	44.78	47.5	39.8	4.57	44.3	33.2	43.3	49.7	23.3	58.2	27.6	30.3	32.9	44.47

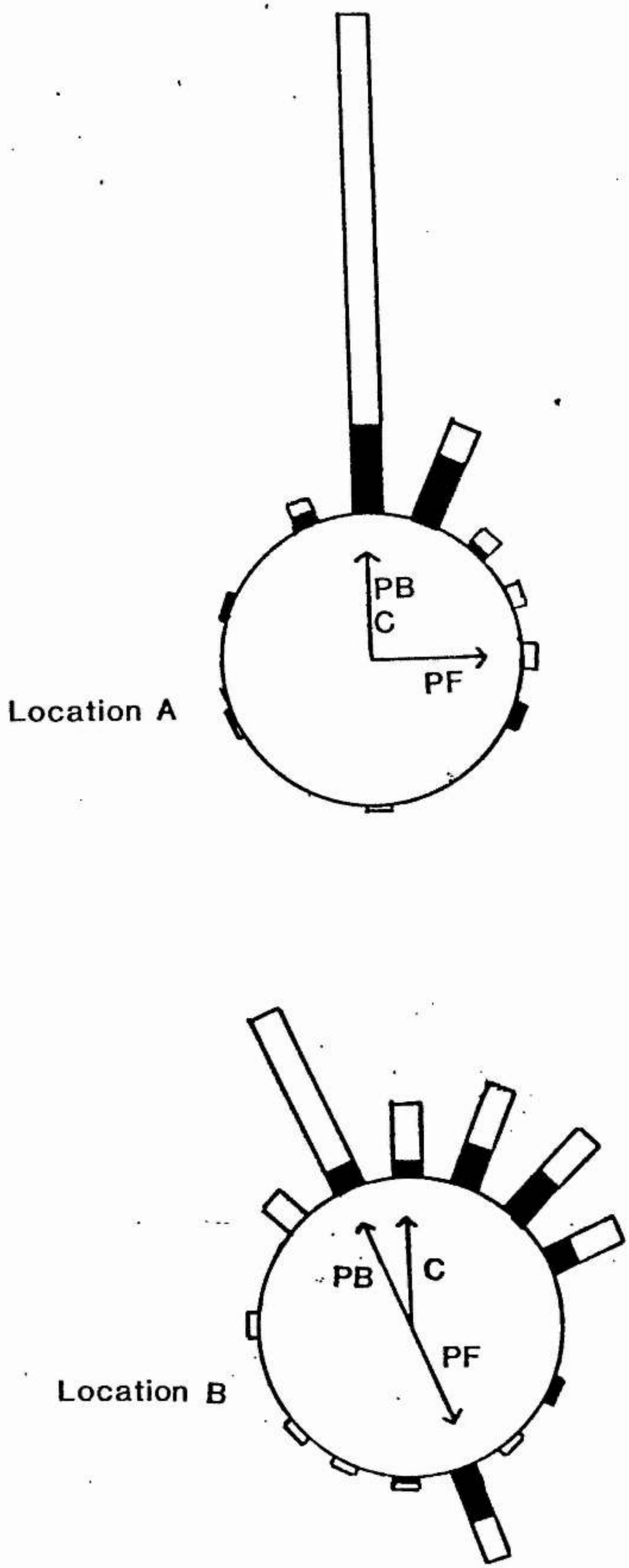
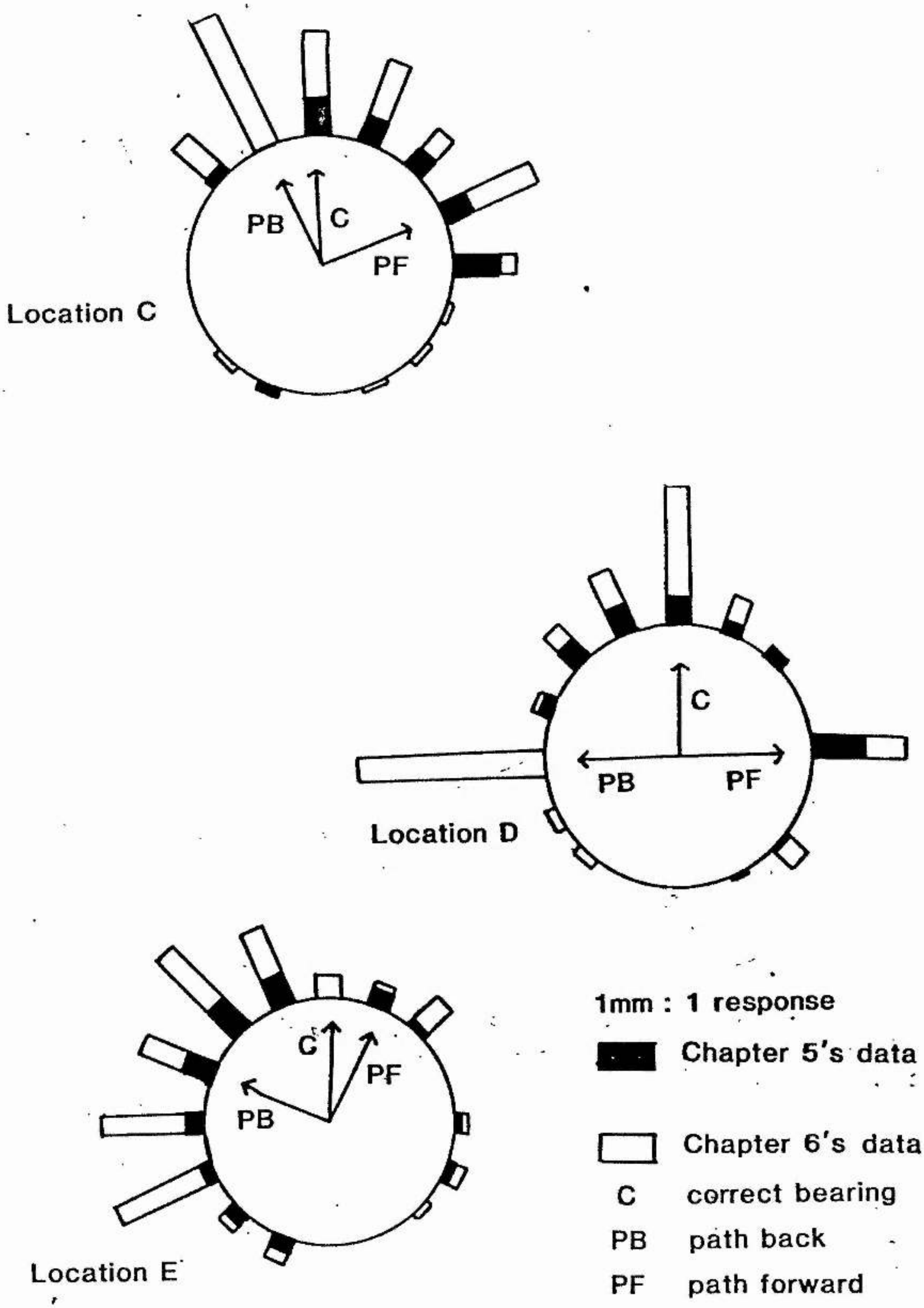


Fig. 14 The distribution of the children's responses at each location


PB
C
PF
Location C
C
PB
PF
Location D
C
PF
PB
Location E
1mm : 1 response
Chapter 5's data
Chapter 6's data
C correct bearing
PB path back
PF path forward

different children as part of the experiment described in Chapter 6, so those scores have been added to Fig. 14 to further clarify the resulting picture. The illustrations show that the children tended to point in the following ways: 1) along the paths, that is, the children pointed back along the path they had just walked down, or along the path ahead of them. These responses will be called 'path responses'. From looking at the distribution of the children's bearings, a range of plus or minus 22.5 degrees from the true path bearing was considered an adequate definition of path responses that is 90 of 360 in all. This range reflects the fact that young children will not always stand exactly where one wants them to when pointing, nor are they able to point very accurately. If the angle between the path and the correct bearing to the target is less than 45°, the response is categorised according to which of the path or correct bearing is closest. The wide distribution of bearings anticlockwise to the 'path back' direction for Location E is probably because there was some genuine ambiguity over the direction of the path, which from child height was partly obscured by a wall when standing at the pointing location. 2) the children made some attempt at pointing through the buildings in the crow-flight direction of the target. An examination of the distribution of the responses revealed that the majority of those which fell around the target were within a range of plus or minus 30 degrees of the true bearing to the target. Responses which fall within this range will be called 'crow-flight responses'. Response which fall outside this range, and which cannot be categorised as path responses will be called 'wild responses'. Whilst wild responses show that the children understood that pointing along the path is not the correct response, and they may have a vague idea of where the target lies, only crow-flight responses can be taken as indicative of Euclidean or vector-map knowledge. Table 14 shows the response types given by each subject on each trial, excluding pointing from location A from which path responses and crow-flight responses are indistinguishable.

The results for each response type in all three trials combined were significantly different from the distribution of responses expected by chance ($X^2 = 23.7$, 2 df, $p < .001$); however, if the trials are examined separately only trial I is significantly difference from chance ($X^2 = 18.5$, 2 df, $p < .01$). Nevertheless, on each trial the pattern of responses is similar. In each case, the distribution of responses is clearly different from that predicted by a hypotheses of only network-map responses, or only vector-map responses, even though this cannot be tested statistically because Chi square tests cannot be carried out in cases where there would be cells with zero in them. If the responses other than path responses are considered alone, the responses for all three trials are significantly different from the pattern of responding expected by chance ($X^2 = 11.1$, 1 df, $p < .001$), with more crow-flight responses than expected. But if the trials are considered separately, only trial I is significantly different from chance ($X^2 = 10.0$, 1 df, $p < .01$). Nevertheless, the pattern of responses in the other trials is in the same direction.

In order to investigate the effect of practice with the experimental environment on whether the children made path responses or

Table 14 The responses given on each trial

	Trial I			Trial II			Trial III		
Subject	Path	Crow-flight	Wild	Path	Crow-flight	Wild	Path	Crow-flight	Wild
♀ 1	2	2	0	0	3	1	0	1	3
2	1	1	2	1	1	2	0	1	3
3	2	1	1	1	1	2	0	1	3
4	0	3	1	1	1	2	3	0	1
5	0	0	4	2	0	2	3	0	1
♂ 1	1	2	1	1	1	2	0	1	3
2	3	0	1	3	0	1	3	0	1
3	4	0	0	2	0	2	3	1	0
4	3	1	0	2	0	2	3	1	0
5	3	1	0	1	1	2	0	3	1
Total	19	11	10	14	8	18	15	9	16

not, an analysis of variance (sex x subject x trial) was carried out on the number of path responses given by each child on each test, excluding responses from location A. There were no significant effects and no significant interactions. Table 15 shows the means and standard deviations of each sex on each trial.

In order to see whether practice with the experimental environment affected the children's ability to make crow-flight responses an analysis of variance (sex x subject x trial) was carried out on the children's crow-flight responses. There were no significant effects and no significant interactions. Table 16 shows the means and standard deviations of response types on each trial.

Unfortunately, systematic records were not made of the children's verbal descriptions of the target location. However, the Experimenter was struck by the fact that the children sometimes said such things as "It's all the way up there and then round the corner" or "It's round there and round there"; such descriptions were followed by path responses. These utterances could be interpreted as verbal descriptions of topological network-map or string-map knowledge.

Discussion

The results of this pilot study show that direction estimates can be used to investigate preschool children's spatial knowledge in natural settings. The children's responses fall into two main types which are parallel to the responses described in Chapter 4: what I

Table 15 Means and standard deviations of path responses

	Trial I	Trial II	Trial III
♀ Mean	1.0	1.0	1.2
Standard deviation	1.0	0.7	1.6
♂ Mean	2.8	1.8	1.8
Standard deviation	1.1	0.8	1.6

Table 16 Means and standard deviations of crow-flight responses

		Trial I	Trial II	Trial III
♀	Mean	1.4	1.2	0.6
	Standard deviation	1.1	1.1	0.5
♂	Mean	0.8	0.4	1.2
	Standard deviation	0.8	0.5	1.1

have called 'path responses' which are when the child points along the path ahead or just walked, instead of the crow-flight direction to the target; and crow-flight responses, when the child points accurately in the crow-flight direction to the target, which is a reflection of Euclidean knowledge. Other responses fall into neither category: the children appear to understand that pointing along the path is not the correct answer, but are unable to give an accurate crow-flight direction estimate. These have been called 'wild responses'. Piché (1977) found a similar distinction between children who pointed along the path and those who attempted the crow-flight direction when she tested five to eight year olds on their knowledge of a housing estate.

Responding by pointing along the path is consistent with string-map or network-map knowledge. Crow-flight responses are consistent only with vector-map knowledge: the amount of error from the true bearing is a measure of error in the vector knowledge. Increased experience with this particular environment led to an increase in overall accuracy but did not significantly effect the nature of the responses made. The ability to make vector-map responses is inconsistent with Siegel and White's (1975) theory of the preschool child as having topological route knowledge only. However, the number of subjects tested in this pilot study is too small for firm conclusions to be made about the nature of preschool children's spatial knowledge. The rest of this thesis will look more closely at the situations in which path and crow-flight responses are made, to see whether the type of response is determined by the nature of the environment or the development of the child;

and will investigate more fully the nature and limits of both path and crow-flight responding. From this it is hoped that a clearer understanding of preschool children's spatial knowledge will be gained.

CHAPTER 6

A comparison of spatial knowledge in two familiar and one novel environment.

Introduction

The previous chapter showed that it is possible to investigate preschool children's spatial knowledge in the real world using a direction estimation task, and found that children's responses include path response, and crow-flight responses. The present chapter looks at whether the kind of response which the children make is affected by the nature of the environment in which the children are tested: will all the children be able to make crow-flight responses given the right kind of environment? In the following experiment, preschool children's spatial knowledge is tested in their homes, and the area around their homes in which they go for walks with their parents. The home and around home area were chosen because, although few direct comparisons have been made between spatial knowledge of these environments and other places, there is some suggestion in the recent literature that more advanced spatial knowledge can be displayed by children in the home and home area than would be predicted from Piaget's, or Siegel and White's (1975) theories of spatial development, and that the home provides an anchor point around which other spatial knowledge is organised. This literature will be examined below. The present chapter also examines whether the type and quantity of knowledge shown differs between a small self-explored environment, and a larger, familiar but passively explored environment. Familiarity (Schouela, Steinberg, Leveton and Wapner 1980; Cousins, Siegel and Maxwell 1983), and self-exploration of the environment (Feldman and Acredolo 1979; Hazen 1982; Biel 1982b) are two factors which have been found to enhance children of all ages' chances of success in other spatial tasks. Thirdly, the present chapter examines whether experience with the procedure of testing itself affects the nature of the children's responses. Does experience with the same task in a familiar environment, where the likelihood of crow-flight responses is maximised, enable the children to then make crow-flight responses in a novel environment? Or does experience with the task per se in a novel environment affect the children's responses on future tests?

Spatial abilities in children's homes. A very few spatial experiments have been carried out in children's own homes. For example, Acredolo (1979) found that nine month old infants tested on a spatial perspective task behaved egocentrically in a landmark-free laboratory and an unfamiliar landmark filled office, whilst those tested in their own homes did not. She suggested various explanations for this, such as that the objects in the home were familiar and so functioned as cues more easily; or that the familiarity of the home provided reassurance, and so enhanced the child's responding. Some support for the former explanation is provided by De Loache and Brown (1983) who asked one and a half to two and a half year old children to find a toy hidden in their home. The children's memory was better for a natural place than for one of a set of metal boxes, although the older children (two to two and a half years) could use the cue of a piece of furniture to find a toy in the right unmarked metal box. However, it could just be that metal boxes are less interesting as hiding places than parts of furniture! Lockman and Pick (cited in Pick and Rieser 1982) tested three to six year olds, eight to nine year olds, and their parents, on their knowledge of the layout of their own apartments, using a pointing task. They found that even the youngest children could perform quite accurately when making judgments to locations on the same floor, but were at a disadvantage in making judgments about the directions of objects on different floors because they had not registered the horizontal displacement of the upstairs rooms.

Spatial abilities in the home area. Several studies have shown that even quite young children can have spatial knowledge of their home area which is much more advanced than the topological route knowledge predicted for children of that age by Piagetian theory. For example, even six year olds are able to produce accurate and consistent sketch or model maps of their own activity range around their home (Biel and Torell 1977; Biel 1979; Hart 1981), and can consistently make distance judgments in the area around their home if they are asked to judge which of two landmarks in closest to various reference sites (Biel 1982a). Anooshian and Young (1981) working with older children of seven, ten, and thirteen years who had been resident in a new housing area for between nine months and thirty eight months, and using a direction estimation task similar to the one used in this chapter, found that although the seven year olds were the least accurate, all the children had general representations of the relative spatial locations of landmarks.

<u>The home as an anchor-point in the organisation of the home area.</u> Several studies suggest that both children and adults organise their spatial knowledge of their home area around their home. For example, Biel 1982b found that six year olds placed their home first on the sketch maps they made of their home area; and Hart and Berzok (1982) talk about a four year old boy who, when building a model of all the places he knew, mentally placed himself inside his home and recreated what he could see from there. Adults may particularly use their home as an anchor point when they are building up knowledge of a new area, as, for example, new entrants to University consistently use their hall of residence as a starting point when asked to make sketch maps of the University Campus, and appear to sequentially add parts to that anchor point (Schouela <u>et al</u>. 1980). Home may be a particularly salient location for blind people, who consistently make less accurate direction estimates than sighted adults, but especially when making estimations from locations other than the home (Byrne and Salter 1983).

However, none of the above mentioned studies compare children's spatial knowledge expressed in their home area with their knowledge of other environments, so it is not known whether such advanced representations are typical of the children's abilities in general, or whether they are unique to the home area for some reason. The following experiment compares young children's ability to make direction estimates in their home area with that same ability expressed in their home, and in a less familiar outside environemnt. The three and four year olds chosen for this experiment are younger than most of the subjects used in the studies mentioned above.

Method

Subjects

The subjects were 24 children (12 boys and 12 girls) who attended playgroups in St. Andrews, Fife. They were divided into four groups, matched on sex, and, as far as possible, on intellectual ability (see below) and age. The children in each group ranged from 3 years 5 months old to 4 years 7 months old, with a mean age of 3 years and 8 months. Seven of the children had previously taken part in the experiments described in Chapter 3.

Materials

1) Large wooden arrow, 2) Silva compass, 3) Scale drawings of the ground floor of each subject's house, 4) Ordnance Survey maps (Scale 1:2500) of each child's home area, and the novel environment, 5) English Picture Vocabulary test (Brimer and Dunn 1973).

General Procedure

Before testing began the experimenter played with each child individually for several hours in order to overcome the child's shyness and establish a relationship. Each child was tested on the English Picture Vocabulary test (EPV), which is a measure of comprehension of spoken words. This provided a means of matching groups on intellectual capacity. The subjects' scores ranged from 88 to 133, with a mean of 111.17 and a standard deviation of 10.4. The mean and standard deviation of ages and EPV scores for each group can be seen in Table 17.

In all experimental environments, the children were taken on a walk with the experimenter, and were asked to point to out-of-sight targets using the wooden arrow as in Chapter 5. The children were encouraged to point the target by being asked to imagine that "everything between them and the target had fallen down so that they could see it and point right to it"; or that "everything in the way had become 'see-through' like windows so that they could see the target and point right to it"; or that "they were superman/wonder woman/a ghost who could walk through walls", and to point the way they would walk to the target. The more anxious children took a very popular glove puppet with them on the walks, or else a sibling who was not allowed to interfere with the response given by the subject. After each test, regardless of accuracy of response, the subject was rewarded with two small sweets or a balloon.

Environments and Test Locations.

The children were tested in two familiar environments: the ground floor of their own home, and the area around their home in which they frequently went on walks with their parent. In each of the familiar environments, the child helped the experimenter to choose 4 targets, but to avoid ambiguity, the experimenter ensured that the locations were such that the angle between the walked-direction and crow-flight direction to the target were as large as possible. In the children's homes, the targets were in different rooms and

Table 17 Means and standard deviations of ages and EPV scores for each group

Group	Age		EPV	
	Mean	Standard deviation	Mean	Standard deviation
1	3.9	0.5	110.7	4.5
2	3.9	0.4	11.3	11.2
3	3.9	0.5	109.5	15.1
4	3.9	0.5	113.2	10.8

were such things as a lamp, or a chair. Some smaller homes allowed only three targets to be chosen. The subject and the Experimenter visited each target to make sure that the child knew its location and was in agreement as to which was the chosen target. The location of each target was also used as a test location for the bearings to the other targets. In the area around the home the targets chosen were out of sight of each other, and also acted as test locations for all other locations. One of the targets had to be the home, and the others were such things as a swing in the park, or the front door of a friend's house. The child was asked to lead the Experimenter to each of the targets, to test his or her knowledge of how to get there, and to check that the child and Experimenter were in agreement over what constituted each target. It was noted whether the targets were visited in an order familiar to the child. The children were tested on one novel environment. This was a simple outdoor route with two approximately right-angled corners. The target was a memorable arch way at the start of the route, and the test locations were specified by the Experimenter along the route.

Design.

All the children were tested in the novel and the two familiar environments: half the subjects received the home test first and half the around home test first, to avoid order effects. The test in the novel environment was repeated three times to test for practice effects. In order to detect any changes in responding caused by experience of the task in a familiar environment, half the subjects were tested in the novel environment before either familiar environment, then between the two, and finally after both. The other half received the novel test only after one of the two familiar environments (and thus were tested on it twice at the end of the series of tests) in order to a) describe preschoolers' naive ability in each environment, and b) detect changes in responding in the familiar environments caused by experience of the same task in the novel environment. Thus, there were four experimental group as follows:

Group 1: Novel test, Home test, Novel test, Around Home test, Novel test.

Group 2: Home test, Novel test, Around Home test, Novel test, Novel test.

Group 3: Novel test, Around Home test, Novel test, Home test, Novel test.

Group 4: Around Home test, Novel test, Home test, Novel test, Novel test.

Results

Scoring.

The Compass bearings measured from the children's responses were compared with the true bearing as obtained from a scale drawing (in the case of the children's homes), or the Ordnance Survey map corrected for magnetic variation. The bearings obtained from the children's pointing responses were converted to errors from the correct bearings as obtained from the scale-drawings of the children's homes, and the Ordnance Survey maps corrected for magnetic variation. Whether the direction of pointing was clockwise or anti-clockwise to the correct bearing was not taken into account: only the difference between the two. The children's responses were categorized into path responses when the children pointed in the walked direction to the target; crow-flight responses, when the children pointed in the crow-flight direction to the target; and wild responses which fell into neither category, using the criteria laid down in Chapter 5.

Previous experimental experience

The total average error score given by each child who had taken part in the experiments in Chapter 4 were compared with those responses made by the children who had not had previous experience. T-tests showed that there was no significant difference between the two groups ($t = 0.57$, 22 df) so the results were collapsed across the two levels of previous experience in all further analysis.

Qualitative analysis

To test whether the children's tendency to make path or other responses was affected by the nature of the environment the percentage of path responses given in each test was analyzed using analysis of variance (group x sex x subject x test). The means and standard deviations for each test can be seen in Table 18.

There was no significant effects of group or sex, but a highly

Table 18 Means and standard deviations of path responses given in each test.

	Test				
	Home	Around Home	Novel 1	Novel 2	Novel 3
Mean	19.8	38.2	69.8	59.4	51.0
Standard deviation	18.8	32.2	35.3	41.6	43.9

significant effect of test ($F = 18.87$, 64 df, $p < .001$). Tukey's HSD tests gave the significant differences shown in Table 19. There were significantly less path responses in the home test than in any of the other tests; significantly less path response in the around home test than in any of the novel environment tests; and significantly less path responses in novel test 3 than in novel test 1. These results are consistent with a hypothesis that increased familiarity with an environment leads to decreased path responding.

In order to ascertain whether the children's tendency to make crow-flight responses was affected by the nature of the environment, an analysis of variance (group x sex x subject x environment) was carried out on the proportion of crow-flight responses made in each environment. There was a significant effect of environment ($F = 19.84$, 64 df, $p < .001$), and no significant interaction.

Table 20 shows the means and standard deviations for each environment. Of the non-path responses, significantly more crow-flight responses were made in each environment than expected by chance (Home: $X^2 = 580$, 1 df, $p < .001$; around home $X^2 = 362.8$, 1df, $p < .001$; Novel 1: $X^2 = 25.4$, 1 df, $p < .001$; Novel 2: $X^2 = 50.0$, 1 df, $p < .001$; Novel 3: $X^2 = 22.3$, 1 df, $p < .001$) Tukey's HSD tests showed that significantly more crow-flight responses were made in the home than in any other environment, and significantly more around home than in the first novel test (all HSD = 19.5, $p < .01$).

To clarify the effect of the environment upon the nature of the response made, all the children's responses in the home, around

Table 19 Significant differences between the percentage of path responses given in each environment (HSD = 17.8, 64 df, $p < .05$; HSD = 21.6, 64 df, $p < .01$)

More path responses

Home	Around home	Novel 3	Novel 2	Novel 1		
–	$p < .05$	$p < .01$	$p < .01$	$p < .01$	Home	Less path responses
	–	$p < .01$	$p < .05$	$p < .01$	Around home	
		–	NS	$p < .05$	Novel 3	
			–	NS	Novel 2	
				–	Novel 1	

Table 20 Means and standard deviations of the proportion of crow-flight responses made in each environment

	Home	Around Home	Novel 1	Novel 2	Novel 3
Mean	65.6	39.2	19.8	29.2	26.0
Standard deviation	22.2	26.2	29.5	26.2	25.0

home, and the novel tests, were analyzed into patterns of responses according to whether they made path responses or not. This of course meant pooling data over different orders of testing, but the lack of significant differences between groups, and interactions between groups and tests made this reasonable. Six patterns emerged as shown in Table 21. The probability of all 24 subjects giving responses which fall only into these six patterns is 6/32 to the twenty-fourth: significantly less than chance. Path responding is lost in the home first, then in the area around home, then in the novel tests in decreasing order of familiarity. However, when the data were analyzed into patterns of response according to whether they made crow-flight responses or other responses, eleven patterns emerged as shown in Table 22. Unlike path responses, there is no neat change in responding according to the environment. The only consistent finding is that crow-flight responses develop first in the home. The two results taken together show that although change from path responding to making other responses happens in a predictable pattern across the environments, whether these non-path responses will be accurate enough to be called crow-flight responses is not predictable, except for the home environment. This suggests that either self-directed exploration, or the small size of the environment, are important for determining crow-flight responses; and that children abandon path responding before they are able to make crow-flight responses.

Quantitative analysis: novel environment

To detect changes in responding in the novel environment due to

Table 21 Patterns of responses, defined by the most frequent response type, where √ indicates crow-flight and wild responses, and X indicates path responses

	Home	Around Home	Novel 3	Novel 2	Novel 1
Pattern 1 (4 subjects)	X	X	X	X	X
Pattern 2 (6 subjects)	√	X	X	X	X
Pattern 3 (4 subjects)	√	√	X	X	X
Pattern 4 (2 subjects)	√	√	√	X	X
Pattern 5 (3 subjects)	√	√	√	√	X
Pattern 6 (5 subjects)	√	√	√	√	√

Table 22 Patterns of responses, defined by the most frequent response type, where √ indicates crow-flight responses, and X indicates wild and path responses.

	Home	Around Home	Novel 3	Novel 2	Novel 1
Pattern 1 (5 subjects)	X	X	X	X	X
Pattern 2 (4 subjects)	√	X	X	X	X
Pattern 3 (2 subjects)	√	√	X	X	X
Pattern 4 (1 subject)	√	X	√	X	X
Pattern 5 (1 subject)	√	X	X	√	√
Pattern 6 (1 subject)	√	X	√	X	√
Pattern 7 (1 subject)	√	X	√	√	X
Pattern 8 (1 subject)	√	X	√	√	√
Pattern 9 (2 subjects)	√	√	X	√	X
Pattern 10 (4 subjects)	√	√	√	√	X
Pattern 11 (2 subjects)	√	√	√	√	√

previous experience in a familiar environment preselected comparisons were made on the errors scores produced in different novel tests, using t-tests, to ascertain 1) whether experience in a familiar environment transfers to a novel one (Groups 2 and 4, novel test 1 versus Groups 1 and 3, novel test 1), 2) whether the type of familiar environment matters or not (Group 2 novel 1 plus Group 1 novel 2 versus Group 4 novel 1 plus Group 3 novel 2). Neither of the t-tests were significant (1) $t = -1.24$, 22df; 2) $t = -0.28$, 22df), suggesting that response accuracy is determined by qualities of a particular environment, and does not thereafter transfer to environments with different qualities. There was a nonsignificant tendency for accuracy to increase over the three tests.

Quantitative Analysis: Comparison of home and around home tests.

If the children's spatial knowledge is Euclidean, one would expect their responses to be commutative; that is, the bearing pointed from target A to target B should be the 180 degree reversal of the bearing pointed from target B to target A. Average divergence from this for each child ranged from 12.6 degrees to 107 degrees, that is, some children's responses were almost commutative, whilst other were not. An analysis of variance on each child's average error from 180 degrees (group x sex x subjects x environments) gave a significant effect of environment only ($F = 24.55$, 16 df, $p < .001$). Table 23 shows the means and standard deviations for each environment. The children's responses were less commutative around home than in the home ($p < .001$). In both the home and around home tests, the more path responses a child made, the less commutative

Table 23 Means and standard deviations of divergence from commutativity

	Home	Around Home
$\bar{x}$	47.6	57.3
SD	87.9	24.8

were his or her responses, but this correlation between average divergence from commutativity and number of path responses given by each child only reached significance in the around home test (Home: $r = .401$, 22 df; Around home: $r = .815$, 22 df, $p < .01$). In both the home and around home the number of crow-flight response was negatively correlated with average divergence from commutativity (Home: $r = -.537$, 22df, $p < .01$; Around home: $r = -.823$, 22 df, $p < .01$). The large range of divergences from commutativity suggest that the children's errors in pointing to the target were random, as opposed to their whole cognitive representation being distorted a consistent number of degrees in one direction.

Quantitative analysis: Home test

As each child's home was different, it is possible that their responses were affected by the size and shape of their house. Therefore, the data were analyzed to see whether each child's error scores were correlated with the direct distance to the target, the number of walls through which the crow-flight direction passed, and the number of corners on the route walked between the two targets. One child (out of 24) produced errors which correlate significantly ($r = .717$, 10 df, $p < .01$) with error flight direction; there were no correlations between average errors and number of walls, and 3 children out of 24 produced significant correlations between average errors and number of corners ($r = .6$, 10 df, $p < .05$ $r = .71$, 10 df, $p < .01$; $r = .58$, 10 df, $p < .05$). No firm conclusions can be drawn from this, but some children, who are not necessarily the youngest, may be working out the way to point by thinking of the twists and turns on the route they would walk between targets (compare Biel 1979).

Average errors within the home ranged from 8.0 degrees to 45.0 degrees, with those who make the smallest average errors making the most commutative responses ($r = .67$, 22 df, $p < .01$). Sixteen children made few (up to three) or no path responses, and made small average errors (less than 30 degrees) that is, most of their responses were crow-flight responses. The mean age of these sixteen children was four years and no months, with a standard deviation of 0.45 years. They possessed knowledge of the layout of their home which contained fairly accurate Euclidean information, that is, knowledge of the direction between locations.

There were no significant correlations between either age of the child, or scores on the EPV test, and either average error scores, number of path responses per child, or number of crow-flight responses per child.

Quantitative analysis: Around home test.

The children's unsigned average errors ranged from 12.6 degrees to 79.4 degrees; those who made the smallest average errors made the least 'path responses' ($r = .82$, 22 df, $p < .01$), and the most commutative responses ($r = .86$, 22df, $p < .01$). Seven children made few or no path responses, and made small average errors, that is, the majority of their responses were crow-flight responses. These children possessed knowledge of the environment around their home which was neither route-like and poorly integrated (Siegel and White 1975), nor topological, static, and egocentric (Piaget et al. 1960; Piaget and Inhelder 1967) but was apparently Euclidean and integrated with fairly accurate knowledge of the position of all four targets relative to each other. These seven children had a mean age of 4.12, and standard deviation of 0.31.

There was a significant negative correlation between the number of path responses per child and age ($r = -.479$, 22 df, $p < .05$). There were no significant correlations between number of path responses and scores on the EPV test; nor number of crow-flight responses or average error scores and either age or scores on the EPV test.

Discussion

The major findings of the experiment are as follows. Firstly, some children aged between 3 years 5 months and 4 years 7 months can show consistent vector-map knowledge. Secondly, the children began to cease relying upon network-map knowledge in the home first, (an environment which is familiar and self explored), then in the area around the home (familiar but passively explored), and lastly in the novel environment (passively explored). Vector-map knowledge is most likely in the home, then in the area around the home, and lastly in the novel environment. Sixteen out of twenty-four children had accurate bearing knowledge of target locations within their own homes. Seven out of twenty-four children had integrated and accurate knowledge of the position of locations within their home area.

Of the others, some seemed to understand the notion of direction but made inaccurate responses. Thirdly, previous testing in either of the two familiar environments had no effect on the accuracy of responses in the novel environment. There is a slight indication that previous experience with the experimental task per se in a novel environment may improve later responding, but this finding was not consistent. Fourthly, within the age range and educational status tested, the ability to make directional estimates, and accuracy of responses, is dependent upon the qualities of the test environment, rather than intellectual capacity or age.

According to Piaget (Piaget _et al_. 1960; Piaget and Inhelder 1967) preschool children should have no knowledge of projective and Euclidean relationships, yet many of the children here can show accurate knowledge of direction in some or all of the test situations. Euclidean knowledge appears to be expressed first in the most familiar environment, and last in the least familiar environment. This finding that the type of knowledge expressed is dependent upon the nature of the environment, questions the concept of stage theory in this area. This is consistent with a view of development which suggests that it does not take place in stages across all domains of knowledge, but that a child's ability is unevenly distributed across tasks (Fodor 1972; Feldman 1980; Fischer 1980) and that the response shown is dependent both on the experience of the child and on the nature of the test situation, in this case the size and familiarity of the environment. This is not to say that no cognitive development is taking place within the child, but what develops is the ability to build up vector-map/Euclidean knowledge in more and more situations.

The few significant differences found between groups of subjects show that the familiarity and size of the test environment had more effect on the children's responses than the order of presentation. The lack of significant findings due to differences in EPV scores again suggests that within the range of intellectual capacity tested, qualities of the environment had a greater effect upon the children's responses.

Those children who were unable to express vector-map knowledge in some situations nevertheless had network-map knowledge, as they were able to lead the experimenter from one target to another. Some children did not rely on network-map knowledge, but their direction estimates lacked accuracy, suggesting that they had not yet built up accurate vector-map knowledge. This is consistent with the literature which suggests that even adults rarely build up spatial knowledge which is an exact copy of the real world (Byrne 1979; Moar and Carleton 1982; Moar and Bower 1983).

In conclusion, it seems that the children's ability to express vector-map or network-map knowledge is affected by the nature of the environment in which they are tested. The experiment described in this chapter confounds size and familiarity of the environment; these two factors will be explored separately in the chapters which follow.

CHAPTER 7

The role of familiarity

Introduction

The previous chapter has shown that preschool children's ability to make directional estimates is dependent upon both the nature of the test environment and the developmental level of the child. However, in that experiment, size and familiarity of the environment were confounded: the home was both the most familiar environment to the child, and the smallest of the environments tested. The following study attempts to experimentally manipulate the children's familiarity with an environment in order to investigate its effect upon their ability to make direction estimates.

Several experimenters have investigated the effect of increasing familiarity with an environment upon the spatial knowledge of subjects of various ages. The results have been mixed. Some studies have suggested that familiarity is important. For example, Cousins et al. (1983) looked at seven, ten and thirteen year olds' knowledge of the layout of their school campus, and found that on a route scaling task in which the subjects had to judge the relative distances apart from each other of locations along a route, and on a bearing estimation task, performance differences appeared to be a function of degree of familiarity with an environment. However, there was an apparent lack of effect of familiarity on performance of landmark and route-order tasks, suggesting that even limited experience was sufficient for the acquisition of those types of representation. That is, degree of familiarity was important for actual spatial tasks as opposed to landmark recognition and knowledge of order. With adults, it has been found that increased experience with an environment leads to increased knowledge of landmarks and routes, until an optimal level has been reached (Herman, Kail and Siegel, in press) but also an increasing likelihood of Euclidean knowledge, which in turn becomes more accurate and 'fine-tuned' with time (Allen, Siegel and Rosinski 1978; Evans _et al_. 1981; Herman _et al_. in press). However, several experimenters working with children have not found that the degree of familiarity with an environment is important. For example, Hazen (1982) looked at two and three year olds' modes and quantity of free exploration in a room in a museum with their parents, and then taught the children the layout of three small collapsible rooms placed in a laboratory. The children were tested on their ability to reverse a learned route, to find an alternative route when a previously used door was blocked, and to find the goal from a novel starting point. She found that the children's spatial abilities were related more to their mode of exploration (children who explored actively rather than passively perform better) than to the amount of time they had spent exploring the environment. Familiarity with a spatial area therefore implies much more than the amount of time spent in an environment. Increased time in an environment may be more valuable to older children and adults because they nearly always explore independently (Hazen 1982). Acredolo _et al_. (1975) tested four and five year olds' incidental and intentional memory for a location where an event had occurred in environments of two degrees of familiarity and two degrees of differentiation. They found that the effects of differentiation and memory task were significant, but the effect of familiarity was not. However, for these children and this particular test - relocating the place where an event occurred - the number of topological cues available to aid their place finding was more important than the amount of experience they had had with the environment because enough information for this particular task could be provided by one trip through the experimental environment. If the children had been tested on a Euclidean spatial task, such as bearing estimation, familiarity may have become an important factor. Nevertheless, there may be instances where spatial knowledge is better for a novel than a familiar environment. For example, Cohen et al. (1979) tested seven and eleven year olds on their knowledge of a novel and a familiar room using three different estimation tasks which required either topological or Euclidean knowledge. They found that the children were more accurate for the novel environment than the familiar environment, and concluded that this was because in the novel environment they were forced to attend to distances. However, each experimental environment consisted of one room containing furniture, and so, although the authors do not state the size of the pieces of furniture, it is possible that spatial knowledge of each environment could be built up from one vantage point rather than from successive views. The degree of familiarity with an environment may become important when spatial knowledge of the environment has to be constructed from successive views. Also, the authors do not state whether the children had had equal experience with the familiar environment, which was the school library. These studies suggest that the type of knowledge tested, the nature of the children's interaction with the environment and the age of the subjects are important determinants in whether the degree of familiarity with the environment will affect the children's spatial knowledge.

Some studies have systematically investigated how familiarity with an environment was achieved: that is, the role of the nature of the child's interaction with the environment, rather than the quantity. There is a general agreement that increasing the number of times the child has to retrieve his or her spatial knowledge, for example, by having to construct a model of the environment several times during the learning phase, improves the child's abilities (Siegel et al. 1979; Herman 1980; Hart 1981). That the environment is learned through active, self-directed exploration (either motor, or visual) is also important (Herman and Siegel 1978; Feldman and Acredolo 1979), although when children have to remember the location of many objects they may be aided by the experimenter drawing their attention to relevant cues (Herman 1980).

In the following experiment, the quantity of experience the children had with the environment was systematically varied, but the nature of that experience was the same for each child. Knowledge of the whole environment had to be constructed from successive views. The aim of the experiment was to test whether repeated experience with an environment could change the subjects from showing network-map knowledge to showing vector-map knowledge. In order to maximise the children's chances of success, the experiment incorporated those elements which other authors have found to increase children's spatial knowledge. The children in the experimental group were given time for active, self-directed exploration of the environment, and had environmental cues pointed out to them by the experimenter. They were repeatedly asked to recall their spatial knowledge throughout the learning phase.

From the design of this experiment, it might be thought that it aims to test Piaget's stage theory of development, but this is not the case. For many years, training experiments were used to discover whether training can accelerate cognitive growth, but a number of criticisms have justifiably been made about such studies, especially by Pinard and Laurendeau (1969). The criticisms are as follows. Without an adequate assessment of the children's initial level of competence, the results are meaningless. If training is successful, one cannot assume that general intellectual growth has occurred, as one may only have trained a specific schema (Goldschmid 1971); nor can one assume that the factor responsible for the acquisition has been tapped. When training fails, it cannot be concluded that training is impossible, only that the methods employed have been inefficient, but neither can one conclude that nature works in another way from that chosen, as the children may be too immature for training to be useful (McCall 1977). Rather than being an attempt to test Piaget's stage theory, the following experiment is concerned solely with the effect of quantity of experience upon the children's spatial knowledge. Contrary to Piagetian training experiments, it does not teach children rules for solving the task, induce cognitive conflict (Kuhn 1974), nor reward the children for the most advanced behaviour, but merely manipulates the amount of experience each child has with the environment.

Method

Subjects

Twenty-eight children took part in the Selection Test. Only eight of these children qualified as subjects for the rest of the experiment, and were randomly divided into two experimental groups the 'Learn Group' (LG) and the 'Non-Learn Group' (NLG). Table 24 shows the mean age and age range of each group. There were three girls and one boy in the Learn Group, and two girls and two boys in the Non-Learn Group. All the subjects have previously been tested on the English Picture Vocabulary (EPV) test (Brimer and Dunn 1973). The small number of suitable subjects meant that the groups could not be matched exactly on EPV scores, although the differences were kept as small as possible. The means and standard deviations of the EPV scores for each subject group can be seen in Table 25. Three of the four subjects in each experimental group had previously taken part in an experiment in Chapter 6. As the number of subjects who had taken part in a previous experiment was balanced across the two experimental groups, no test for the effect of previous experience was considered necessary. All the children were members of playgro-ups in St. Andrews and were familiar with the experimenter.

Apparatus

1. Four toys: a monkey glovepuppet, a crow glovepuppet, a plastic

Table 24 Mean age and age range of each subject group

Selection Group	Age	
	Mean	Range
LG	3:11	3:7 - 4:7
NLG	3:7	3:3 - 3:9
Select test only	3:10	3:2 - 4:0

Table 25 Means and stadard deviation of EPV scores

	Selection test only group	Learn Group	Non-Learn Group
Mean EPV	110.4	113.0	114.5
Standard deviation	11.3	14.1	10.1
N	20	4	4

spoon, and a crayon.

2. Four large flowerpots in which to hide the toys.
3. Architect's plans of the experimental areas, scale 1:100.
4. Wooden arrow for pointing.
5. Silva compass.

General Procedure

The children were tested individually. The procedure at each part of the experiment was identical. Each child was familiarized with the toys and asked to name them: the name given by the child was used throughout the experiment. The children were told that they and the Experimenter were going to play a hiding and pointing game with the toys. The Experimenter said, "I want you to remember very carefully where each of the toys is hidden because I've got a terrible memory, so if you don't remember, we might lose the toys forever". The Experimenter told the children where to hide each toy in its flowerpot, and pointed out some of the things near to it in order to help the children remember the location. The children were then led back through the environment and the experimenter drew their attention to each hidden toy. The subjects were then encouraged to explore the environment on their own for the next three minutes, and reminded to look in each flowerpot as they passed. The experimenter and children then went to each toy in turn, from which the subjects were encouraged to point directly to each of the toys, which were out of sight, using the wooden arrow. Encouragement to point directly was given in a similar manner to the methods outlined in previous chapters, for example, "I want you to imagine that all the walls have gone see-through like windows so that you can see the ___ and point right to it". The bearing of each response was recorded. The locations chosen in each environment remained the same throughout the whole experiment, but which toy was placed at which location was randomly varied, so that the children were not just learning a rote response. The children were rewarded with a small sweet at the end of each session regardless of the quality of their performance.

Procedure

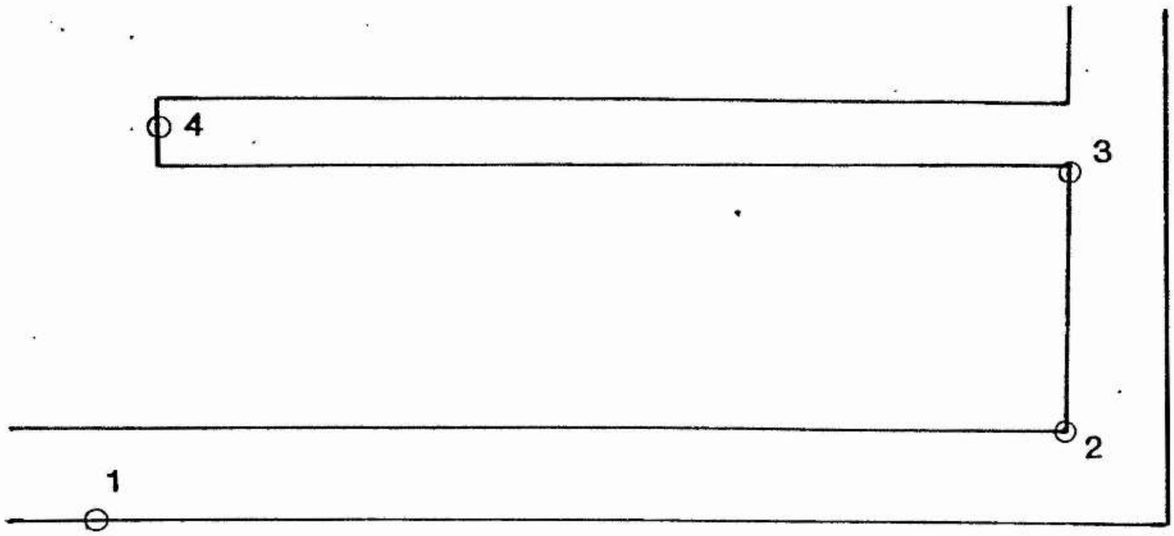
Table 26 shows a summary of the experimental procedure for each subject group. At the selection test, only those subjects who made at least five path responses out of six trials at pointing to out-of-sight objects were chosen for the experimental groups. All the experimental subjects took part in Test 1. The time between Test 1 and post-tests was, as near as possible, two weeks for each subject. In the interim period LG took part in Test 2 to 4. The order in which the children were tested on the two post-tests was balanced across the subjects in each group.

The experimental environments were novel to the children and were corridors in the Department of Psychology, University of St. Andrews. The environment used in the Selection Test can be seen in Fig. 15. Tests 1 to 5 were all carried out in one environment (Fig 16), which was of approximately equal size and shape to the Selection Test environment. The Different Shape Post-test was carried out in an environment of approximately the same size, but a differ-

Table 26 Summary of Experimental Procedure

	Subject Group		
Test	Selection test only Group	Learn Group	Non-Learn Group
Selection Test	✓	✓	✓
Test 1		✓	✓
Test 2		✓	
Test 3		✓	
Test 4		✓	
Order balanced { Post-test: Test 5		✓	✓
Post-test: different shapes		✓	✓

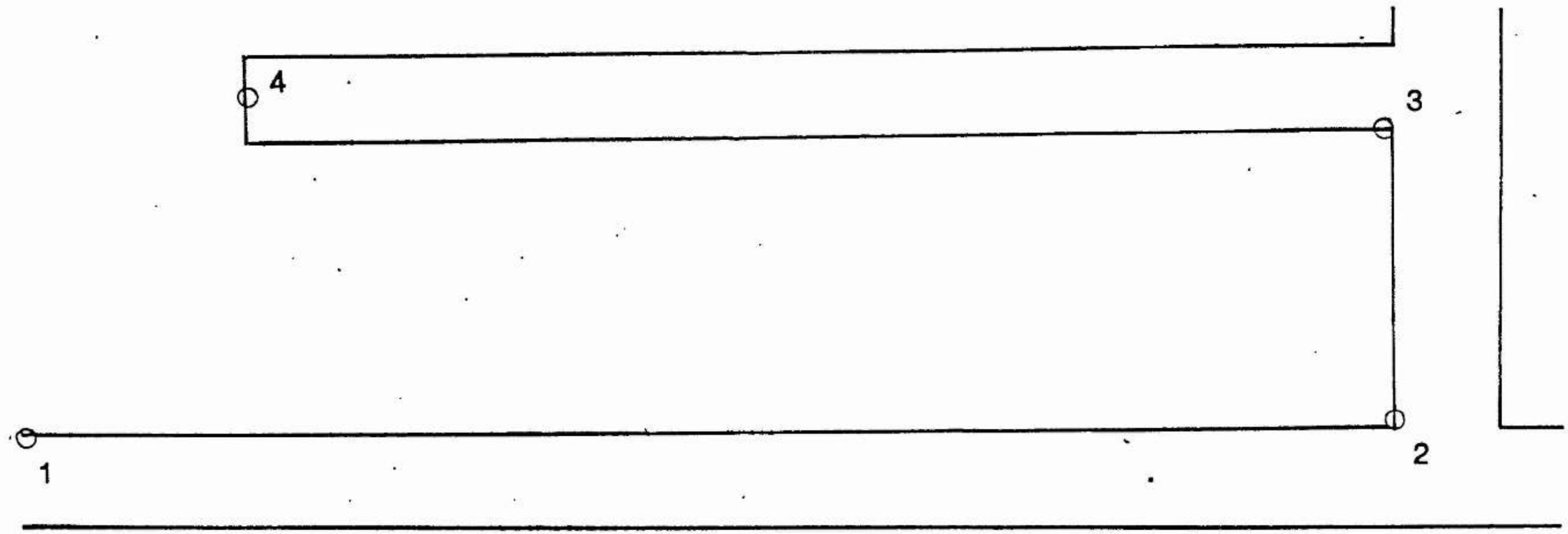
Fig. 15 Selection test environment



○ object location

Scale 1:100

Fig. 16 Pretest, learning, and same shape post test environment



O object location

Scale 1:100

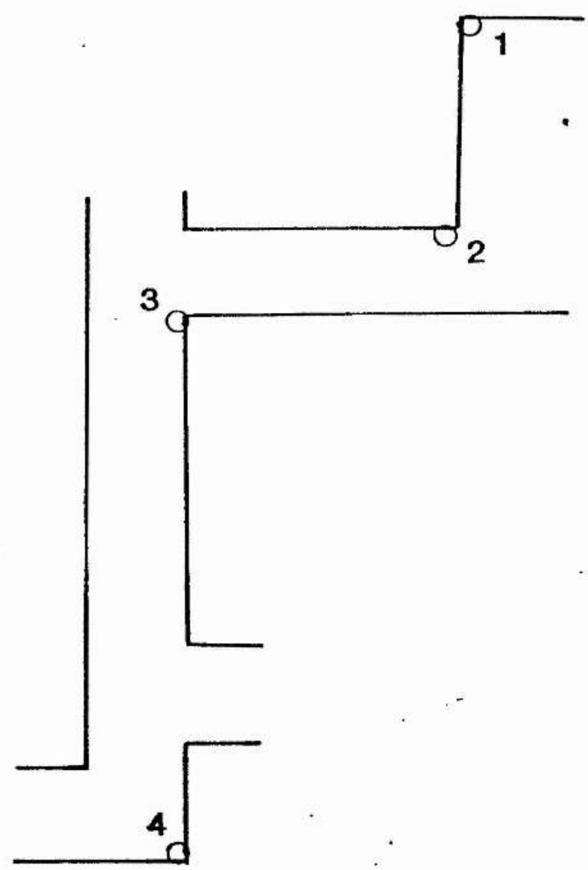
ent shape (Fig. 17).

If familiarity with an environment affects the nature and accuracy of the children's responses in that particular environment, then LG should make less path responses, more crow-flight responses and smaller average errors in pointing on the same shape post-test than the NLG. If increased experience with the direction estimation test affects children's spatial skills in a general way, then LG should make less path responses, more crow-flight responses, and smaller errors than NLG on the different shape post-test also.

Results

The children's responses on the 'same' and 'different' environment post tests were categorized as path or crow-flight responses using the criteria laid down in Chapter 5. To test the hypothesis that familiarity affects the children's tendency to make path responses, an analysis of variance (group x order of testing x subject x environment) was carried out on the number of path responses given by each child in each environment. The means and standard deviations of the number of path responses made by each group in each environment can be seen in Table 27. There were no significant effects of either group (LG versus NLG), order in which the subjects received the two tests, or environment (same shape versus different shape), and no significant interactions. Increasing the quantity of experience a child has with a particular environment therefore appears to have no effect either on the number of path responses a child makes in that particular environment, nor does it have a gen-

Fig. 17 Different post test environment



○ object location

Scale 1:100

Table 27 Means and standard deviations of number of path responses

	LG		NLG	
	Same	Different	Same	Different
Mean	4.5	3.8	5	4.3
Standard deviation	1.7	1.0	1.2	1.0

eral effect on the number of path responses a child makes in a different shaped environment. The proportion of path responses in each condition was so high that the lack of significant results could be due to ceiling effects.

In order to ascertain the effect of familiarity with the test environment on the children's tendency to make crow-flight responses, an analysis of variance was carried out (group x order of testing x subject x environment) on the number of crow-flight responses made by each child. No significant effects or interaction were found. Table 28 shows the means and standard deviations of crow-flight responses for each group. The proportion of crow-flight responses in each condition was so small that the lack of significant differences is probably due to floor effects. In both environments, Chi square goodness of fit tests showed that of the non-path responses less crow-flight responses were made than expected by chance.

The children's errors from the true bearing were calculated, as was the mean error for each child: the sign of the error was not taken into account. As there were so few crow-flight responses, the data cannot be considered bimodal in distribution, therefore an analysis of variance (group x order x subjects x environment) was carried out to test the hypothesis that familiarity with an environment effects the accuracy of the children's responses. No significant effects were found for group (LG versus NLG), or the order in which the children received the two tests, but there was a significant effect of environment ($F = 18.49$, 4 df, $p < .02$) with smaller errors

Table 28 Means and standard deviations of crow-flight responses

		LG	NLG
Same	Mean	0	0
	Standard deviation	0	0
Different	Mean	0.8	0.5
	Standard deviation	1.0	1.0

being made in the 'different' environment than in the 'same' environment. There were no significant interactions. Table 29 shows the mean and standard deviations of the errors made by each group in each environment. The significant difference between the overall size of the errors made in each environment is probably because the mean angular difference between the true and path bearing is smaller for the 'different' environment than it is for the 'same' environment (Different 27.7 degrees; Same 58.3 degrees). Although no significant effect was found for groups, from Table 29 it appears that larger errors were made by NLG in the same environment than by LG in the same environment, whilst the scores for the two groups in the different environment were almost identical. The difference between the groups in the same environment suggests that experience with an environment may have a specific effect of decreasing the size of errors in that environment, and probably did not reach significance because of the small number of subjects in each group.

Discussion

The results suggests that increasing the amount of experience a child has with an environment does not affect the nature of the children's directional estimates in that particular environment, or in general. However, there was a nonsignificant indication that experience with a particular environment may have a specific effect of decreasing the size of errors in that environment. However, this was not felt worth pursuing because of the difficulties of design and implementation with this experiment. There are many problems in interpreting the results found here. Firstly, it can only be con-

Table 29 Means and standard deviations of errors

	LG		NLG	
	Same	Different	Same	Different
Mean	54.7	43.6	66.5	42.6
Standard Deviation	23.6	5.4	6.9	12.0

cluded that the amount and kind of experience provided by this experiment did not significantly change the children's abilities to make directional estimates. Even though the aim was to provide experience with the environment in a way that would maximise the children's chances of success, drawing on the findings of previous researchers as described in the introduction, it is still possible that no effects were found because in 'real life' familiarity with an environment happens in a different fashion. The LG children experienced only three more learning sessions than NLG. Although no more sessions were possible because by this time the children had become bored with the task, this quantity of extra experience with the environment may not have been sufficient to effect a significant difference in responding between the two groups. Secondly, it is possible that the LG children's responses did not change during the course of the experiment because they had learned that making a path response was apparently sufficient to satisfy the experimenter. Why bother to make the extra effort to infer the crow-flight direction to the target, even if this is within one's capabilities, if your experience on previous sessions has shown that this is not necessary? This interpretation is supported by the children's boredom towards the end of the experiment: bored children will make the quickest and easiest response in order to finish the experiment and obtain a sweet. Thirdly, only eight children out of twenty-eight qualified as members of the experimental group. It is possible, therefore, that the lack of significant results was due to the very small number of subjects. The fact that 71% of the children managed to make more than one vector-map response on the selection test suggests that something about the environment made the task particularly easy: this may well have been the size of the environment, as it was roughly equivalent to the distances between the targets in the children's homes in the previous chapter, and smaller than any of the outdoor environments used in this thesis. The next chapter will look at the effect of environmental size on the nature and accuracy of the children's responses. Fourthly, perhaps too strict a selection criteria was adopted for the experimental subjects. Fifthly, it could be argued that there were no significant results because it is difficult or impossible to systematically control a child's familiarity with an environment in a laboratory setting, and there is more to building up familiarity than increasing exposure time (Acredolo 1982). Placing children in an environment does not of course guarantee that they will become familiar with that environment. Providing a theme or story which functionally relates objects in an environment has been found to facilitate children's spatial representations (Cohen and Cohen 1982; Herman and Roth 1984). However, as mentioned in the introduction to this chapter, care was taken to maximise the children's chances of learning about the setting. Ideally, familiarity should be investigated in more naturalistic settings, such as Siegel and Schadler's (1977) study of children's knowledge of their playschool classroom after two or eight months of experience with the classroom. However, it is very difficult to avoid confounding experience with a 'real-life' environment and age of the subject. Also, the children may have had different qualities of experience with the environment: several studies in 'real-life' settings have shown that there are individual and situational differences in the quality and nature of children's explorations of environments which affect their spatial knowledge (Hazen 1982;

Henderson *et al.* 1982).

This experiment has been unsatisfactory because of the many faults and difficulties mentioned above. However, it can be tentatively concluded that there is some indication that increasing children's experience with a particular environment increases the accuracy of their responses in that same environment only.

CHAPTER 8

Does environmental size affect spatial knowledge?: a comparison of two 'large-scale' sites.

Introduction

The previous two chapters have suggested that the size of an environment may affect the nature and accuracy of preschool children's directional estimates. The present study aims to investigate this experimentally by examining the children's ability to make bearing estimates in two indoor environments of approximately the same shape, but different sizes. One was chosen as approximately equivalent in size and distance between targets to the children's houses in Chapter 5, and the other as being comparable in size and distance between targets to the outdoor environments in Chapter 5. Two indoor areas were selected (as opposed to one indoor, one outdoor) so that there was tighter control over their shape, and to avoid any possible confounding of affects due to the external or internal nature of the environment. Both environments were 'large-scale' by the definitions of Acredolo (1981) and Siegel (1981): that is, they surrounded the individual, and required that a cognitive representation was built up from a number of observations from different positions, rather than being perceived simultaneously from one vantage point. On the basis of the findings of Chapters 6 and 7, it was hypothesized that the children would make more crow-flight responses and less path responses in the smaller environment than in the larger environment. However, this effect would be due to how long it takes to walk round each environment, and consequently the length of time the child has to hold the position of one location in memory before reaching the next. The present experiment aimed to separate the effect of time it takes to walk round an area from the size of that area by controlling the speed at which subjects moved from location to location. Previous experimentation with children and adults has suggested that time to walk round an area is related to distance estimations (Herman, Norton and Roth 1983).

Several authors have previously made comparisons between children's spatial knowledge in different sized environments, but their experiments were carried out in order to compare different methods of testing spatial knowledge, rather than having comparison of size as their aim. For example, they have been concerned with differences between children's performance in room-sized environments and table-top sized environments (for example, Acredolo 1977), and their ability to translate their knowledge from one of these sizes to the other, (for example Siegel et al. 1979; Liben et al. 1982; Blades and Spencer, in press). As tests of environmental size, their findings are not relevant here because their methods and aims are so diverse as to render them beyond comparison, and because they involve a totally different scale of environment to the present study. No researchers, to my knowledge, have compared performance on two different sized large-scale environments. As tests of methodology, they are discussed in the relevant section of Chapter 2.

Method

Subjects

The subjects were twelve boys and twelve girls, who were members of two playgroups in St. Andrews, Fife. Their ages ranged from 2 years 10 months to 4 years 2 months (Mean = 3.38; Standard deviation = .35). All the subjects were familiar with the experimenter who had played with them at playgroup and visited them at home. They had all been tested on the English Picture Vocabulary test (EPV) a test of comprehension of spoken vocabulary (Brimer and Dunn 1973). All of the children had previously taken part in the experiment described in Chapter 9. The subjects were divided into four experimental groups matched as far as possible on age, sex, and EPV scores. Table 30 shows the means and standard deviations of age and EPV scores for each group.

Apparatus

1. Detailed architect's plans of the two experimental environments.
2. Wooden arrow for pointing, adapted with two upright markers placed one at either end in series.
3. Toys for the smaller environment: toy adult and baby tortoises, paper apple, box of straw.
4. Toys for the larger environment: pull-along train, passenger for train, tunnel, coal bunker.

Experimental Environments

The smaller environment consisted of corridors in the basement

Table 30 Means and standard deviations of ages and EPV scores for each experimental group

Group		Age	EPV
L/SS	$\bar{x}$	3.33	105
	SD	0.40	7.71
L/NS	$\bar{x}$	3.45	107.67
	SD	0.47	17.18
SS/L	$\bar{x}$	3.36	107.83
	SD	0.25	6.31
NS/L	$\bar{x}$	3.39	110.17
	SD	0.33	12.98

of the Department of Psychology, University of St. Andrews (Fig. 18). The larger environment was formed from corridors in the Physics Building, University of St. Andrews (Fig. 19). The environments were chosen as approximately equivalent in shape, but differing in size.

Procedure

The four experimental groups were as follows:

Large/Slow small group (L/SS) - experienced the larger environment first, then the smaller environment at a slow walking pace.

Large/Normal small group (L/NS) - experienced the larger environment first, then the smaller environment at a normal walking pace.

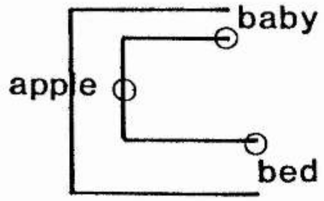
Slow small/Large group (SS/L) - experienced the smaller environment first at a slow walking pace, then the larger environment.

Normal small/Large group (NS/L) - experienced the smaller environment first at a normal walking pace, then the larger environment.

Practice Session

The subjects were tested individually. Each child first attended a practice session, in which they were familiarized with the toys to be used in the experiment. The children were introduced to the toys from each environment separately in the order that they would encounter the environments. The children were asked to name each of the toys, and the name they chose was used throughout the experiment. With the smaller environment's toys, the children practised pulling the adult tortoise along, placing the baby on its back

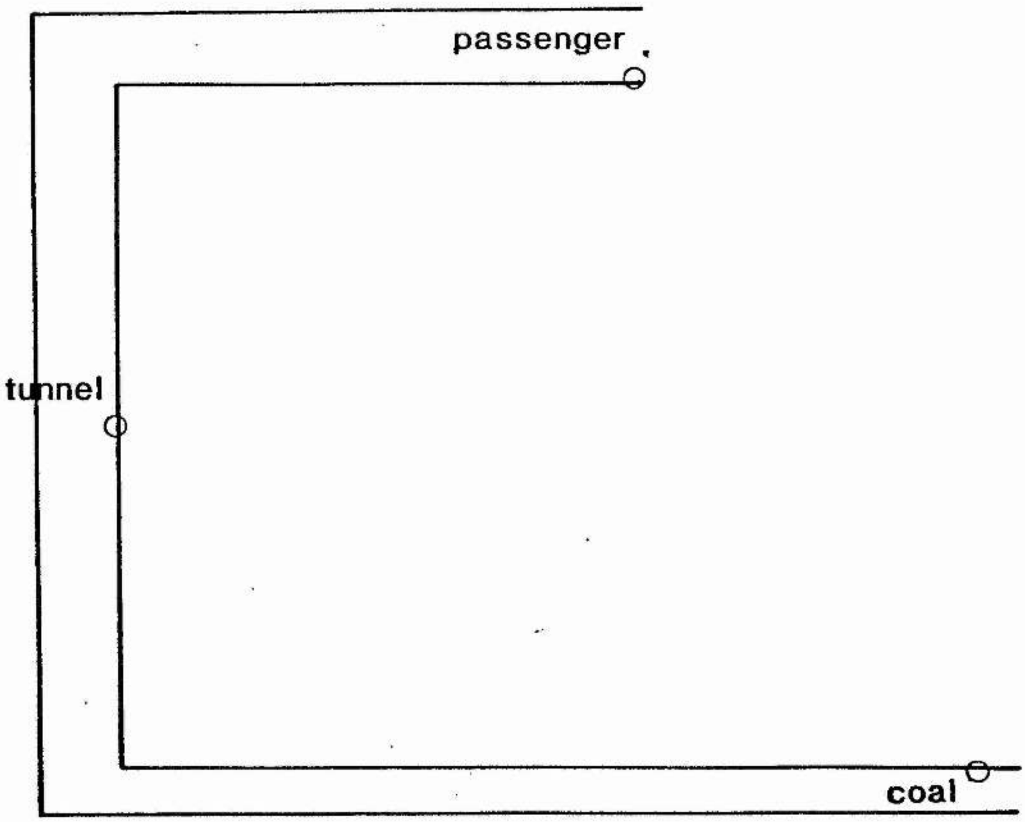
Fig. 18 Smaller environment



○ target location

Scale 1:305

Fig. 19 Larger environment



O target location
Scale 1:305

and taking it for a ride, making the adult eat the apple, and putting the tortoises to sleep in the straw bed. The children in the two 'slow' groups (L/SS and SS/L) were taught to pull the tortoise along very slowly, at such a speed that it would take as long to walk between each location in the smaller environment as it would to walk between each location in the larger environment. This was introduced by the experimenter saying, "Do you know something very special about the way that tortoises walk?" to which the child would answer no or yes as appropriate. "They can only walk very very slowly. We are going to take the big tortoise for a walk, and I will show you how to make her walk very very slowly". The Experimenter then demonstrated, and the children practised until they did it with ease. With the larger environment toys, the children learnt to pull the train along, place the passenger in the train and take it for a ride, fill the train with coal from the coal bunker, and make the train go under the tunnel. The toys and activities were chosen to be roughly equivalent for each environment.

Learning Phase. The children encountered the two experimental environments in the order determined by their group. For each child, there was one week between each test , except where illness necessitated a slightly longer time period. In each environment the children watched the experimenter place the three toys other than the pull-along train and big tortoise in their appropriate locations (See Figs. 18 and 19) and they then walked round the environment five times more (a total of three times in each direction) at the appropriate speed. In the smaller environment they put the small tortoise on the other's back, took it for a ride, fed the tortoises the apple, and put them in the bed, or the reverse. In the larger environment, they put the passenger in the train and took it for a ride, went under the tunnel, and filled up with coal, or the reverse.

Test phase: The larger test environment was unfortunately found to be highly magnetic, so the children's direction estimates could not be measured with a compass in the usual way. The smaller environment was not magnetic, but the same procedure was used in both environments as follows. The child pointed with the arrow. The Experimenter looked along the arrow, and lined up the two markers on the top of the arrow. The exact location to which the arrow pointed was noted (for example, the fifth coatpeg from the left) and this location was marked on a very finely detailed architect's plan. The children pointed from each location to the other two locations, and were encouraged to make crow-flight direction estimates by the methods used in the previous chapters. The children were rewarded with a balloon at the end of each session, regardless of performance.

Results

For each response, a pencil line was drawn on the architect's plan between the location from which the child pointed to the location to which she or he pointed, and also to the true location. The angle between the two was then measured and recorded as the error score (plus or minus signs were not taken into account). The children's responses were also categorised into crow-flight, path and wild responses using the criteria laid down in Chapter 5.

To determine the effect of environmental size on subjects' tendency to make path responses, two analyses of variance (order x sex x subject x environment size) were performed on the number of path responses given by each child in each environment. In one analysis of variance, speed was constant in the two environments (that is, groups L/NS and NS/L), whilst in the other, time was constant in the two environments (that is, groups L/SS and SS/L). Tables 31 and 32 show the means and standard deviations for each group. When speed was constant there was a significant main effect of environment size only ($F = 17.05$, 8 df, $p < .01$), with more path responses being made in the larger environment than in the smaller environment. No other main effects or interactions were significant. When time was constant, there was also a significant effect of environment ($F = 11.53$, 8 df, $p < .01$) with more path responses being made in the larger environment than in the smaller environment. However there was also a significant interaction between order of testing, sex and environment ($F = 8.47$, 8 df, $p < .02$). Tukey's HSD tests showed that the males in L/SS, and the females in SS/L, gave more path responses in the large environment than were given by the SS/L males in either environment (HSD = 3.63, 8 df, $p < .01$), or by the SS/L females in the small environment (HSD = 2.72, 8 df, $p < .05$).

No significant correlations were found between scores on the EPV test and the number of path responses or crow-flight responses given in either the larger environment, the smaller environment, or both environments combined. A significant negative correlation was

Table 31 Means and standard deviations of path responses with speed constant

	Larger environment		Smaller environment	
Group	Mean	Standard Deviation	Mean	Standard Deviation
L/NS ♂	5.0	1.0	3.3	2.31
L/NS ♀	5.0	1.73	2.7	0.58
NS/L ♂	3.3	2.52	2.0	2.0
NS/L ♀	4.0	2.65	3.3	3.1

Table 32 Means and standard deviations of path responses with time constant

	Larger environment		Smaller environment	
Group	Mean	Standard deviation	Mean	Standard deviation
L/SS ♂	6.0	0.0	4.67	1.15
L/SS ♀	5.0	1.73	4.67	1.53
SS/L ♂	2.3	1.53	2.33	2.31
SS/L ♀	6.0	0.0	3.0	1.73

found between age and the number of path responses given in the small environment ($r = -.45$, 23 df, $p < .05$): that is, the older children made less path responses in the smaller environment. No significant correlations were found between age and either the number of path responses given in the larger environment, nor in both environments combined; and no significant correlations were found between the number of crow-flight responses given in either or both environments and age. In order to ascertain the effect of environmental size on the children's abilities to make crow-flight response, two analyses of variance (group x sex x subjects x environment x response type) were carried out. In one, speed was constant in the two environments (L/NS and NS/L), whilst in the other, time was constant in the two environments (L/SS and SS/L). Tables 33 and 34 show the means and standard deviations for each group. When time was constant, there was a significant effect of environment ($F = 15.13$, 8 df, $p < .01$) with more crow-flight responses being made in the smaller environment than the larger environment; and a just significant interaction between group and sex ($F = 5.78$, 8 df, $p < .05$). Tukey's HSD tests on the interaction between group and sex produced no significant differences. In the smaller environment, for responses other than path responses, more crow-flight responses were made than expected by chance ($X^2 = 8.2$, 1 df, $p < .01$). Crow-flight responding in the larger environment was at chance level. When speed was constant, there were no significant effects and no significant interactions. In both environments significantly more of the non-path responses were crow-flight responses than expected by chance (Large: $X^2 = 11.5$, 1df, $p < .01$; Small $X^2 = 10.6$, 1 df, $p < .01$).

Table 33 Means and standard deviations of crow-flight responses with time constant

		Larger environment	Smaller environment
L/NS ♂	Mean	0.3	1.0
	SD	0.6	0.0
L/NS ♀	Mean	0.7	1.0
	SD	1.2	0.0
NS/L ♂	Mean	0.7	2.7
	SD	0.6	0.6
NS/L ♀	Mean	0	1.3
	SD	0	1.2

Table 34 Means and standard deviation of crow-flight responses with speed constant

	Larger environment	Smaller environment
L/SS ♂ Mean	0.3	0.7
SD	0.6	0.6
L/NS ♀ Mean	1.0	0.3
SD	1.7	0.6
NS/L ♂ Mean	1.7	2.0
SD	2.1	2.7
NS/L ♀ Mean	0.0	1.3
SD	0.0	1.2

The children's average error scores in each environment were correlated with their EPV scores and ages. No significant correlations were found between scores on the EPV test and the children's average error scores in either the larger environment or the smaller environment. A just significant negative correlation was found between average errors in the larger environment and age ($r = -.416$, 22 df, $p < .05$); and between average errors in both environments combined and age ($r = -.375$, 46 df, $p < .01$). In both the larger environment, and the two environments combined, the younger the child, the larger their average error. There was no significant correlation between size of error and age in the smaller environment. There were no significant correlations between average error scores and either age or EPV scores in each environment, or both environments combined, for each sex separately.

Discussion

The most important results of this experiment are as follows: 1) The size of the environment was important in determining the nature and accuracy of these preschool children's responses. The subjects made less path responses in the smaller environment than the larger environment, and more crow-flight responses in the smaller environment than the larger environment when time to walk round the environments was constant. 2) The nature and accuracy of the children's responses are not correlated with their scores on the English Picture Vocabulary test. 3) In the smaller environment, the older the children the less path responses they made.

The effects of environmental size on the nature and accuracy of the children's responses support the hypotheses laid down in the introduction to this chapter, that the children would make less path responses, and more crow-flight responses in the smaller environment. However, the difference between the environments in the number of crow-flight responses made was only significant when time was constant, and not when speed was constant. The different effects of environmental size upon the children's spatial knowledge cannot therefore be due to how long it takes to walk round each environment, a finding contrary to the results for distance estimations by other authors (Herman et al. 1983). However, it seems more likely that distance should be based on time to travel between locations than should direction.

In conclusion, given two large-scale environments which differ in their size but not in their shape, preschool children are more likely to rely on vector-map knowledge, and less likely to rely on network-map knowledge in the smaller environment than in the larger.

CHAPTER 9

Is path responding a uniform phenomenon?: an investigation into an inability to make directional estimations

Introduction

Throughout this thesis, the children's directional estimations have been categorized as path responses or crow-flight responses and the two kinds of pointing have been considered as a test of Byrne's (1979, 1982) network-map/vector-map theory of spatial knowledge. However, it is possible that different kinds of knowledge, or different reasons for that particular response, may be hidden within each category. The present chapter aims to look more closely at what it means to be a path responder, by examining the children's responses in a rectangular environment bordered by a walked path, and bisected by a path which is never walked by the subjects, but which is a potential short or alternative route to certain locations. The next chapter will study the nature of pre-school children's vector-map responses.

What kinds of spatial knowledge could cause a child to make path responses? Table 35 outlines all the types of spatial representations which are theoretically possible, from string knowledge to vector knowledge, and the type of response which would be predicted from each. The aim of the following experiment is to discover which of these theoretically possible responses the children made, and thereby whether categorizing children as path responders hides a

Table 35 Hypothesized possible response types

Possible categories	Type of representation	Expected response
String knowledge	Topological - knowledge of walked routes only as discrete and separate routes.	Present experiment cannot distinguish between these two responses; both expect the child to point to all targets along the path the child walked, in the direction walked.
One-way network-map	Topological - integrated knowledge, of walked routes, coded in walked direction only.	
Two-way network	Topological- combined knowledge of walked routes, coded in either direction.	Child should point along the walked path, but in either direction.
Path-bias vector-map	Euclidean - child 'has' Euclidean knowledge, but expresses it by pointing along the most direct path.	Child points along the most direct path to the target whether that path has been walked or not.
Vector-map	Euclidean	Child points in crow-flight direction to the target.

variety of spatial representations.

An experimental environment was chosen which provided the opportunity for pre-school children to express as many of these different kinds of knowledge as possible.

Method

Subjects

The subjects were twelve girls and twelve boys aged between two years ten months and four years two months. (Mean age three years four and a half months). The children were all members of playgroups in St. Andrews, Fife, and none of them had taken part in any previous experiments. However they were all familiar with the Experimenter, as they had played with her in the playgroup, been visited by her in their own home, and been tested on the English Picture Vocabulary (EPV) test (Brimer and Dunn 1973), a test of comprehension of spoken vocabulary. Their EPV scores ranged from 93 to 139, with a mean score of 107.75, and standard deviation of 11.2.

Apparatus

1. Three small plastic animals: cow, sheep, horse.
2. Wooden arrow for pointing.
3. Silva compass for measuring bearings.
4. Scale plan of chosen environment.

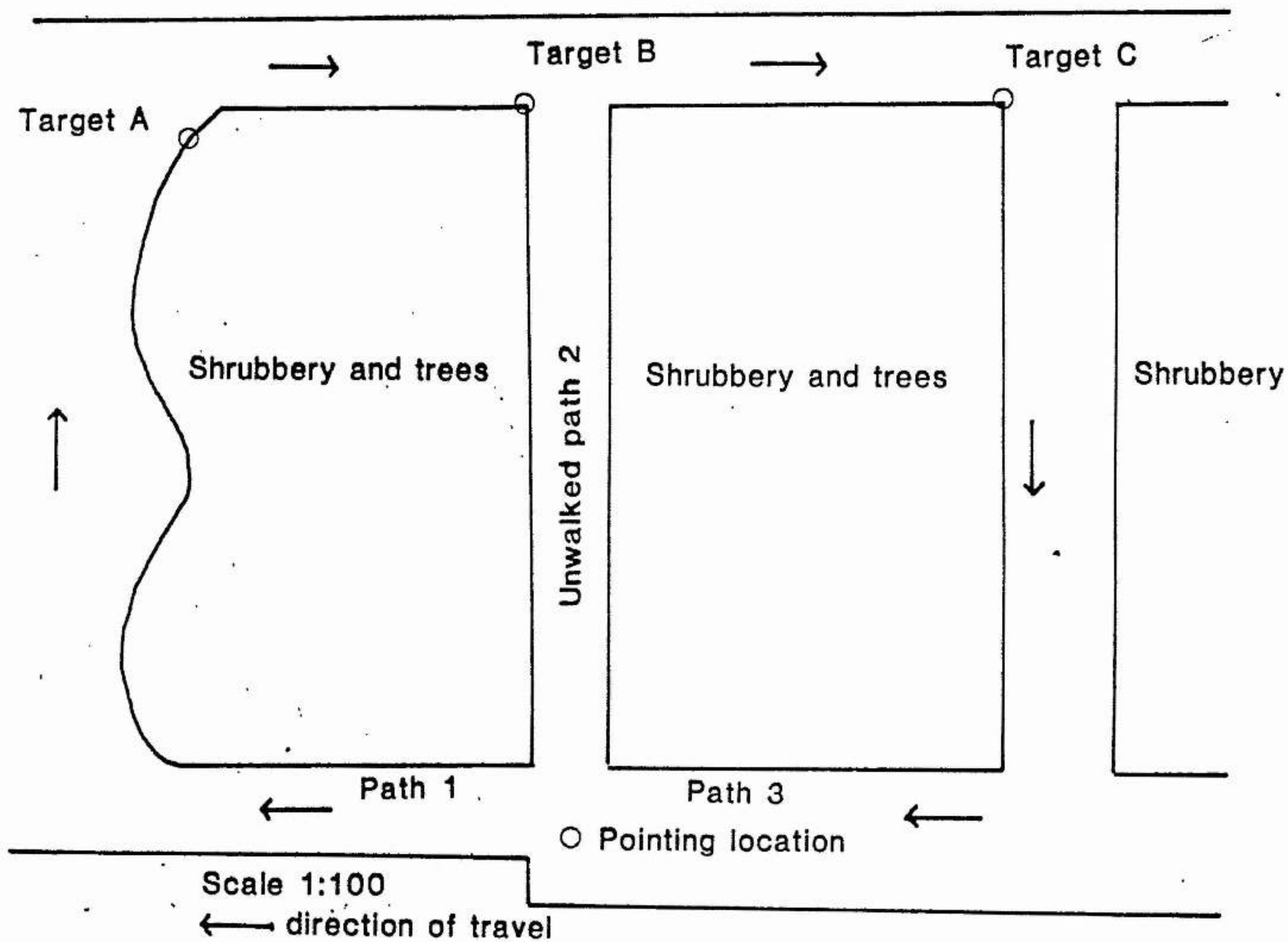
Experimental Environment

A plan of the chosen experimental environment can be seen in Fig. 20, which also shows the target locations, and route taken by the children. It consisted of paths laid out in a small formal garden, in which large shrubs grew in the flowerbeds so that the paths were hidden from each other. The environment was novel to all the children.

Procedure

The children were taken individually to the garden to be used in the experiment, and stood on the pointing location. The Experimenter told the children that they were going to play a hiding game with some toy animals. The animals were shown to the children who were asked to name them: the names given by each child were used throughout their test. The children were told that they were going to hide the animals, and the Experimenter would show them where. The children were then led round the route in the direction shown in Fig. 20, and hid the animals in the locations indicated. The Experimenter then asked the children if they could go on the same walk and find the animals without being told where they were. The children set off round the route and found the animals, with the Experimenter following behind and helping where necessary. When back at the pointing location again, the Experimenter said, 'Let's see if you can hide the animals in the same places again all by yourself without me showing you where to put them. The children set off round the route again to hide the animals, and the Experimenter fol-

Fig. 20 Experimental environment



lowed and helped where necessary. Finally, the children were asked to find the animals again. In total the children walked round the route and attended to the locations four times, and they were all capable of finding their way along the learned route to each of the locations by the end. When finally back at the pointing location, the Experimenter said, 'Let's see if you can point to the places where we hid the animals. But, oh dear, we cannot see the places from here because the trees and bushes are in the way. So let's pretend that the gardener has come along with an axe and chopped all the trees and bushes down so that we can see the animals' hiding places and point right to them. Can you pretend you can see the ___'s hiding place? Can you point to it?' Each time the children were asked to point to a hiding place they were shown the animal which had hidden there, to make sure they were not confused over which animal was which. Each child pointed with the wooden arrow to all three target locations, and the bearings were measured with the compass, and noted down. All the children appeared to enjoy playing the 'game', and frequently asked if they could do it again. They were all rewarded with a balloon at the end of the experiment regardless of performance.

Results

The children's responses were categorized as path or crow-flight responses using the criteria laid down in Chapter 5. There were no wild responses. The children's errors from the true bearing were also calculated (plus and minus signs were not taken into account) if they made crow-flight responses.

From the hypothesized categories of spatial knowledge and their expected responses (Table 35), specific predictions were made about the children's responses in the experimental environment and these are shown in Table 36. The children's responses to each location were categorized according to Table 36, and the results are shown in Table 37. The most frequent response types were one-way network knowledge, path-bias vector-map knowledge, and both path-bias vector map and true vector-map response made by the same child.

In order to discover whether the responses given by the children correlated with their age or scores on the EPV test, each child's three responses were analyzed individually. Table 38 shows a break-down of the responses given to each individual target. The types of responses were ordered in assumed increasing sophistication of knowledge as follows: walked direction path response, opposite direction path responses, unwalked path response, and Euclidean response. Each type of response was then assigned a value from one to four respectively. Every child could then be given a total response score. These were correlated with age, and with scores on the English Picture Vocabulary test. There was a just significant correlation with age ($r = .398$, 23 df, $p < .05$), but a nonsignificant correlation with EPV scores ($r = .387$, 23 df). Within this particular environment, the older the children, the more advanced response they make. To test for sex differences, a t-test for independent samples was carried out on the total response scores obtained by the boys and the girls. No significant difference was found (girls 83: boys 85). The sex of the child therefore appeared to have no effect on their responses.

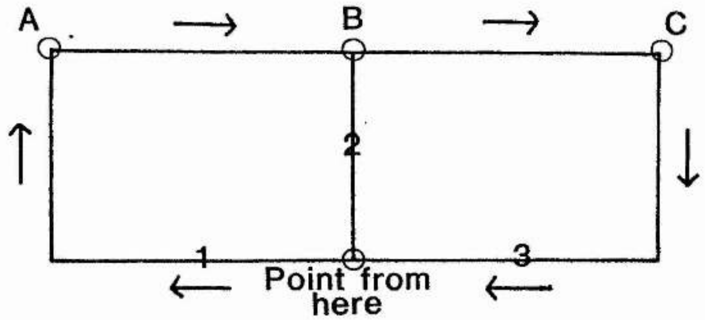
Table 36 Responses predicted by each category of spatial knowledge

Spatial knowlege	Child Points:		
	Location A	Location B	Location C
One-way network or string knowledge	Path 1	Path 1	Path 1
Two-way network knowledge	Path 1	Path 1 or 3	Path 3
Path-bias vector-map knowledge	Path 1 or 2	Path 2	Path 2 or 3
Vector-map knowledge	Direct to A	Path 2	Direct to C

Table 37 Types of responses given by the children

Actual response types	Number of children	Percentage of children
String or 1-way network	6	25%
2-way network	1	4.2%
Both 1-way network and path-bias vector-map	1	4.2%
Path-bias vector-map	6	25%
Both path-bias vector-map and vector-map	5	20.8%
Vector-map	5	20.8%

Table 38 Responses made to each target



<table>
<tr><th></th><th>Target A</th><th>Target B</th><th>Target C</th></tr>
<tr><td>Path 1</td><td>16</td><td>6</td><td>8</td></tr>
<tr><td>Path 2</td><td>2</td><td rowspan="2">19</td><td>1</td></tr>
<tr><td>Euclidean</td><td>6</td><td>8</td></tr>
<tr><td>Path 3</td><td>0</td><td>0</td><td>6</td></tr>
</table>

Discussion

The main findings of this experiment are as follows: 1) children with vector-map knowledge sometimes express it by pointing along a path; 2) those children who do not have vector-map knowledge, use network- or string-maps which contain knowledge in the direction of travel only: that is, they are 1-way networks not 2-way; 3) the sex of the children has no apparent effect on their responses.

A quarter of the children apparently made path responses because they possess only string-map or network-map knowledge. Such maps were coded in the direction of travel only, (except for one child, a finding which could have occurred by chance). Byrne's (1982) description of network knowledge implies unidirectional coding, and Moar and Carleton (1982) found that knowledge of an environment learnt by watching slides was biased towards the direction of travel. The present study, for preschool children at least, provides experimental evidence to support Byrne's (1982) supposition, and shows that 1-way knowledge is not an artifact of slide presentation. This finding is contrary to Rowan and Hardwick (1983) who found no apparent effect of direction travelled on the spatial abilities of five and a half year old children. However, in their study, the Experimenter started the children on the unbranching route so all they needed was to know when to stop at the target location. This could be solved using the topological cue of 'next to' only. Network-map knowledge, as found in the present experiment, is topological, and contains no information about crow-flight direction or distance between locations, and is therefore consistent with Piaget's (Piaget et al. 1960, Piaget and Inhelder 1967; Piaget 1977) and Siegel and White's (1975) predictions about the spatial knowledge of the two to four year old children tested here. However, 21% of the children gave crow-flight responses only, and therefore had Euclidean spatial knowledge (Byrne's (1979, 1982) vector-map knowledge). Such responses are inconsistent with the type of knowledge predicted by Piaget, and Siegel and White. However, a large percentage of children expressed knowledge which lies between these two extremes: path bias Euclidean knowledge or a mixture of this with true Euclidean knowledge. It therefore seems that there are some preschool children who are able to build up Euclidean knowledge of the environment tested here, but the expression of that knowledge is restricted to walkable routes. Since they are able to point in the direction of the target if it lies along an unwalked path, it seems most probable that their inability to express their Euclidean knowledge with a crow-flight response is due to the presence of the barrier between them and the target. However hard one pretends that the gardener has chopped down all the trees and bushes, or that all the walls have fallen down, for example, the fact remains that one does not walk through bushes or walls to get to a target when perfectly adequate paths are available. This of course means that in much previous work, including some of my own in this thesis, the children could have been misinterpreted as having network-map knowledge, or poor spatial knowledge in the case of the other authors, when in fact they were expressing their Euclidean knowledge by pointing along the nearest path to the target. Mixed responders are beginning to lose this reliance upon paths, but it is still there to some extent. Thus Byrne's (1979, 1982) hypothesized dichotomy of spatial ability remains intact: the difficulty lies with the children's ability to express their Euclidean knowledge. Two-thirds of the children therefore have Euclidean knowledge of this particular environment: a figure which provides substantial disconfirmation of traditional stage theories of spatial development (Piaget et al. 1960; Piaget and Inhelder 1967; Siegel and White 1975).

Nevertheless, within the age range tested, there was an apparent increase in Euclidean knowledge with age. This finding is consistent with the results of the rest of this thesis, and does not oppose the suggestion from previous chapters that both age and the nature of the environment determine the child's response. The apparent lack of sex differences is contradictory to some previous authors who have suggested a male superiority in spatial tasks (for example, Keogh 1971; Munroe and Munroe 1971; Spencer and Weetman 1981), but this sex difference has been found particularly on tasks which require manipulation of spatial knowledge (for example, Anooshian and Young 1981; Harris 1981), and is not supported by all authors (for example, Miller 1978; Pearce 1981).

In conclusion, the results support Byrne's (1979, 1982) network-map/vector-map theory of spatial knowledge, and provide experimental evidence for his implication that network knowledge is coded in one direction only. Preschool children's Euclidean knowledge is either expressed by crow-flight responses, or is restricted to walkable routes. However, these path responses are not tied to travelled routes, or the direction travelled, unlike those which are the result of network-map knowledge.

CHAPTER 10

A comparison of adults' and children's vector knowledge.

Introduction

Throughout this thesis it has been found that preschool children are able to show vector-map or Euclidean knowledge in some situations, and that what apparently develops is the ability to build up such knowledge in more and more situations. The aim of the following chapter is to look more closely at the preschool child's Euclidean knowledge. By comparing the children's performance with that of adults on the same spatial task, it is hoped that it will be discovered whether the child's apparent vector-map knowledge is identical to that of the adult, or only superficially so, perhaps being built up via a different process, for example. Siegel and White (1975), and Siegel, Kirasic and Kail (1978), have argued that the acquisition of route schema is a vital stepping-stone towards an adults' final cognitive map of an environment. This implies that if we learn two intersecting routes through an area, we will first acquire a separate schema for each route. In contrast, Moar and Carleton (1982) have produced experimental evidence which suggests that if two such routes are learned, they are immediately integrated into a network representation of the two routes. In the following study, which investigates children's and adults' directional knowledge of locations along two intersecting routes, within and between route judgements will be compared in order to examine whether or not two subject groups have integrated the two routes. If the two routes are coded separately, then within-route errors in direction estimates should be smaller than between-route errors. If the two routes have been integrated, then there should be no difference in the accuracy of within- and between-route judgments.

Spatial knowledge, particularly in towns which are structured by streets, is by necessity built up from our encounters with paths between locations. The crow-flight direction between locations has therefore to be inferred. Such vector information could be built up by two different processes (Moar and Carleton 1982): either the locations are spatially laid out to take into account the directions and turns of the paths, with this spatial knowledge becoming more accurate as learning occurs (spatial map hypothesis) or else, when we initially learn a route, we build up a linear sequence of associations containing information only about the serial order of landmarks and directions of turns (sequential hypothesis). With experience of the route, the sequential representation becomes more complex, more and more associations are made, the representation becomes more accurate and well defined and eventually may take on map-like properties (Moar and Carleton 1982). The sequential hypothesis predicts that during the initial acquisition of a route, direction estimates should be more accurate in the direction of travel along the route than in the opposite direction, because the relations between landmarks on the route are initially encoded in the direction of travel. In contrast, the spatial-map hypothesis predicts that direction judgments should not differ significantly depending on whether or not they are in the original direction of travel along the route, because landmarks on the routes are represented in a format with map-like spatial properties. Moar and Carleton (1982), having tested adults on their knowledge of an environment learned through the presentation of slides, found evidence to support the sequential hypothesis, as the subjects' direction and distance estimations were significantly more accurate for landmarks which lay in the direction of travel than they were for landmarks opposite to travel. However, this finding could have been partly due to the fact that the presentation of a 'slide walk' is more tightly unidirectional than a real walk: walkers through an environment can turn their head for a wider field of view, or even look behind them. The following study looks at whether there is evidence for sequential learning of vector properties of a walked environment, and at whether adults and preschool children differ in their reliance upon sequential or spatial learning. To test this, direction estimates to locations to which the shortest path is in the learned direction of travel will be compared with direction estimates to locations to which the shortest path is opposite to the direction of travel. A simple forward to travel/backward to travel distinction, as in Moar and Carleton (1982), cannot be made in this study as each route formed a closed rectangle, all locations therefore can eventually be reached in the same direction of travel.

Method

Subjects

The subjects were ten children and ten adults, seven females and three males being in each age group. The children's ages ranged from four years three months to five years three months, with a mean age of four years and eight months. The adults' ages ranged from twenty two years six months to thirty four years six months (mean twenty five years and ten months). The children were members of playgroups in St. Andrews, Fife, and had all taken part in a previous experiment in which they had shown themselves to be the most competent and consistent vector-map responders. They were therefore familiar with the Experimenter. The adults were all research students and staff from St. Andrews University, Fife. All the subjects had previously been tested on the English Picture Vocabulary (EPV) test (Brimer and Dunn 1973), a test of comprehension of the spoken word.

The children's scores on the English Picture Vocabulary test ranged from 109 to 140, with a mean of 120.4. The adults' scores ranged from 107 to 133, with a mean of 127.3. The adults and children therefore have similar scores. This test incorporates an age adjustment until the age of eighteen years, after which no correction for age-score co-variation is made.

Apparatus

1. A large wooden arrow, with which the subjects made their responses. 2. A silva compass, to measure the subjects' responses. 3. An ordnance survey map of the chosen environment, scale 1:2500.

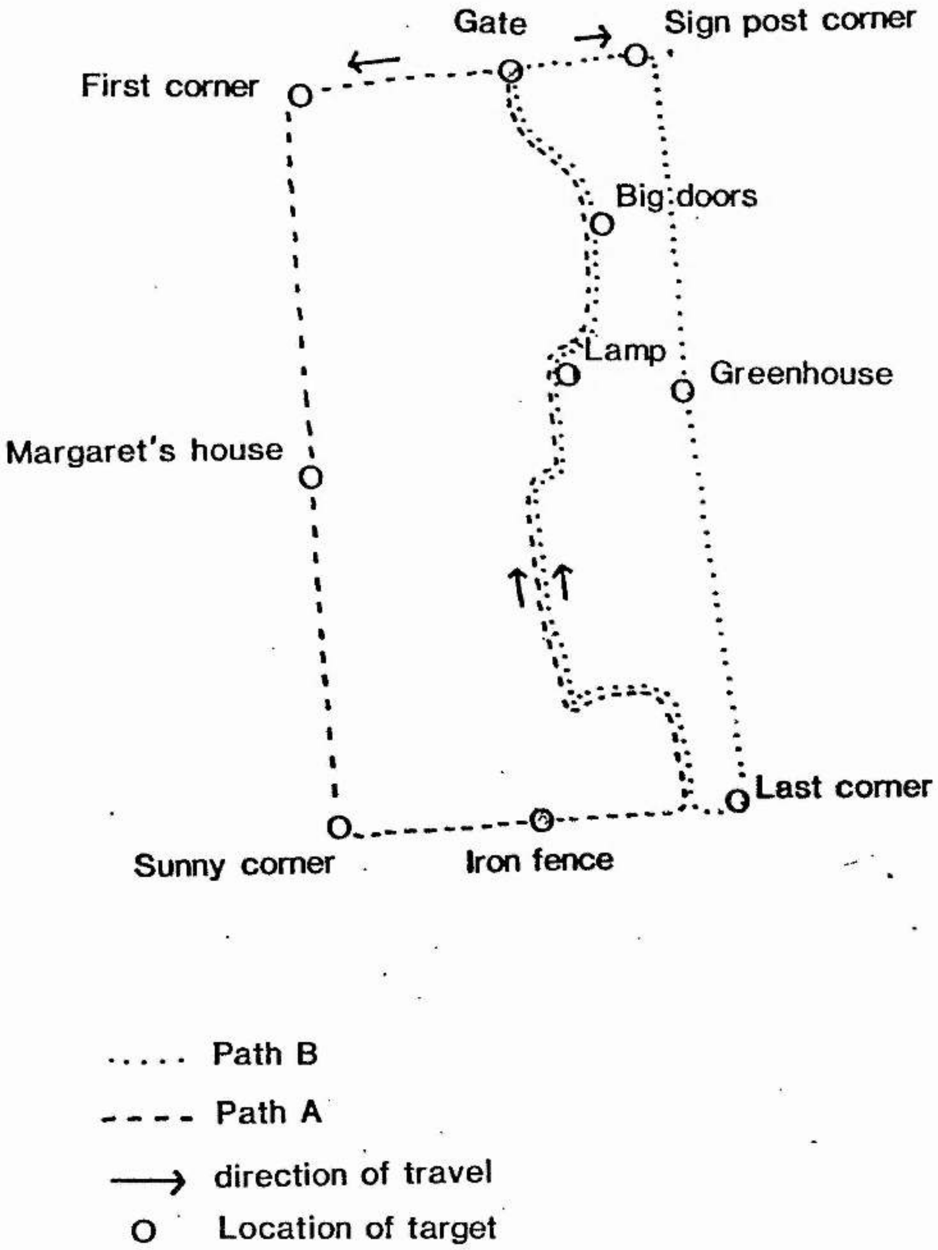
Routes

The two paths chosen can be seen in Fig 21. Together they form a rough figure of eight, and intersect at the middle. The part of the town from which the paths were chosen was not completely novel to either the children or the adults. Both routes started by the 'Big Doors' (Fig 21). The paths were walked in the same direction. Although the Lamp, the Big Doors, and the Gate were encountered on both walks, the Gate was pointed out and used as a location from which to point only on Path A, while the Lamp and Big Doors were pointed out and used for a location from which to point only on Path B

Procedure

The procedure was the same for both the children and the adults. The subjects were told that they would be coming to see the Experimenter several times, and that when they came they would go on two walks. Along the walks, the Experimenter would point out and name several places, and they were to try and remember both the names of the places and where they were. The subjects were taken on the walks individually by the Experimenter. In each session both paths were walked, separated by ten minutes in which the subject was taken inside, and talked with the Experimenter on a completely different subject, and in the case of the children played with two glo-

Fig. 21 · Experimental routes



vepuppets. At this point, the children were rewarded with a small sweet regardless of performance to encourage their continued cooperation: the adults were offered the same reward, but seldom accepted! Each subject visited the Experimenter on four occasions: the sessions were on consecutive days where possible, or otherwise as close together as was convenient for the subject. In session one, the subject walked the two routes with the Experimenter, who stopped at and named each chosen location, and asked the subject to repeat the name. In session two, the subject and Experimenter walked the two routes, and the subject was asked to find and name each of the locations, with the Experimenter helping where needed. From each location, the subject was asked to point with the wooden arrow to one other predetermined location. The subjects were told that this was just for practice, and that as they were still learning the positions of the locations, it did not matter if they had some difficulty in making the direction estimates. If they had difficulty in remembering the location they were reminded of which locations it was near and what it looked like. If the children initially made a path response, which was very rare, they were encouraged to make a crow-flight response by the methods used in previous chapters. The bearings of the subjects' direction estimates in this second session were measured, but were not used in the main analysis of the experiment. In each of sessions three and four, the test sessions, the subjects made two or three direction estimates from each location, so that by the end of the two test sessions, two separate and different direction estimates had been made to each location. For each path there were two possible sets of direction estimates to be made. The order in which the subjects were tested on these sets was randomized across the subjects, with the proviso that both paths were walked by each subject in each session. At the end of each session, the children were rewarded with a balloon: this reward was not contingent upon the quality of their performance.

Results

Comparison of Session Two (Learning session) with Sessions Three and Four

In previous chapters, the number of path responses and crow-flight responses made in each environment have been analyzed separately. However, in the present chapter, the children were selected because of their previously shown tendency to make crow-flight responses, and the adults were expected to be able to make crow-flight responses. Table 39 shows the percentage of crow-flight, path, and wild responses made in the Learning and Test sessions. As expected, the large majority of responses were crow-flight responses, and there were very few path responses. If the frequency of occurrence of each responses type in each environment were examined here as in previous chapters, it is unlikely that significant results would be produced because of ceiling and floor effects. It is therefore more appropriate to examine the size of subjects' errors. The subjects' errors from the true bearings were calculated. The range of errors made in the Learning and Test sessions can be seen in Figs. 22 and 23. Responses to locations in sight were ignored. In both sessions, the distribution of responses appears to be unimodal around the true bearing: it is therefore appropriate to analyse results using analysis of variance. To test for differences between the adults' and childrens' responses in the two sessions, an analysis of variance (subject group x subject x session) was carried out on the subjects' average errors in each session. Average error scores were calculated without taking into account whether the error was clockwise or anti-clockwise of the true bearing (that is, the sign). Responses to targets in sight were also ignored. The results gave a significant effect of subject group only ($F = 16.46$, 18 df, $p < .001$), with significantly larger errors being made by the children than by the adults. There were no other significant effects or interactions. Table 40 shows the means and standard deviations of average error scores for the children and adults in each session.

Comparison of within- and between-path errors

The locations for the comparison were chosen such that, as near as possible, the angles, distances, and nodes between each pointing location and target were equivalent across path types, and the subjects' errors in making these responses were calculated. The range of errors made can be seen in Fig. 24. The responses appear to be unimodel around the true path bearing, so it is therefore appropriate to analyse the error scores using analysis of variance. An analysis of variance was carried out on the subjects errors (subject group x path type x location), but the signs of the errors were not taken into account. The results gave a significant effect of path type only ($F = 5.63$, 18 df, $p < .05$), with within-path errors being significantly larger than between-path errors. No other effects or interactions were significant. The means and standard deviations of the within- and between-path error scores can be seen in Table 41. The finding of significantly larger errors for the within-path responses is counter to the theory that a separate schema is made for each route, and suggests that the two routes have been integrated into a network re-

Table 39 Distribution of response types per session

% of responses			
	Crow-flight	Path	Wild
Session 2	71.7	3.8	24.5
Sessions 3 & 4	71.2	8.0	20.8

Fig. 22 Session 2 : Range of errors

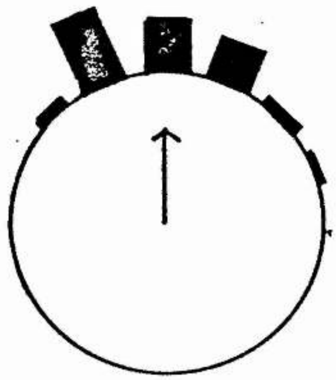
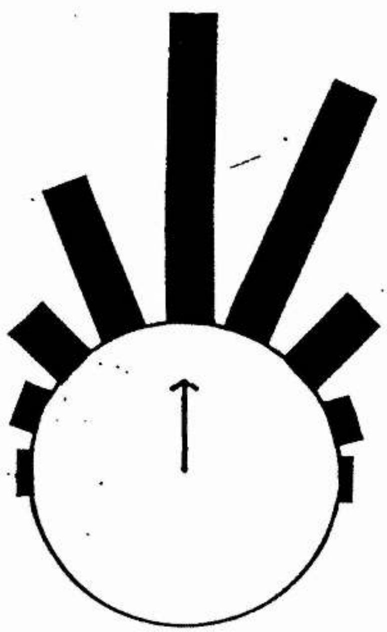


Fig. 23 Sessions 3 and 4 : Range of errors



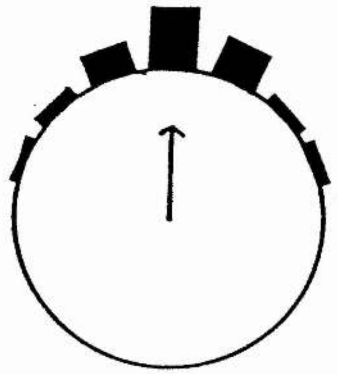
⟶ true bearing

1mm : 5 responses

Table 40 Mean and standard deviation of average error scores

		Learning Session	Test Session
Child	$\bar{x}$	30.7	29.6
	SD	12.1	5.2
Adult	$\bar{x}$	19.8	20.2
	SD	6.5	3.1

Fig. 24 Range of within- and between-path errors



⟶ true bearing

1mm : 5 responses

Table 41 Mean and standard deviation for within and between path errors

		Children	Adults
Within Path	Mean	24.23	19.30
	Standard deviation	20.65	15.73
Between Path	Mean	17.07	15.33
	Standard deviation	15.11	8.81

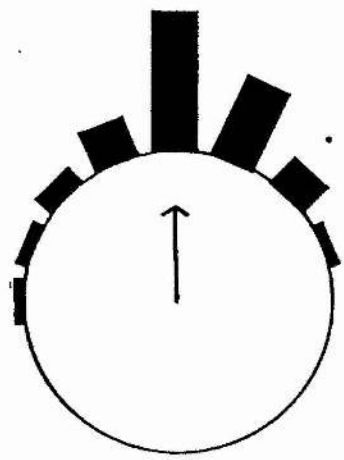
presentation.

Comparison of in direction of travel and opposite to travel direction responses

The locations for this comparisons were chosen such that the angles between each pointing location and target were as near as possible equivalent for the two direction types, and so that for each direction type there was an equivalent number of targets which were one, two, and three locations away from the pointing location. The subjects' errors in making these responses were calculated. The range of the errors can be seen in Fig. 25. The errors appear to be unimodally distributed around the true bearing, so it is therefore appropriate to analyse the responses using analysis of variance. Analysis of variance (subject group x direction type x distance x location) gave significant effects of subject group (child/adult) ($F = 7.55$, 18 df, $p < .05$), direction to travel ($F = 5.62$, 18 df, $p < .05$) and of number of nodes between pointing location and target ($F = 13.63$, 36 df, $p < .0001$). No other effects were significant, and there were no significant interactions. Table 42 shows the mean and standard deviations of the error scores for each direction of travel.

As expected, the children made larger errors than the adults ($p < .05$). Smaller errors were made when pointing to targets situated in the direction of travel than were made when pointing to targets situated opposite to the direction of travel ($p < .05$) which supports the hypothesis that information is stored according to the direction

Fig. 25 Range of errors forward and backward to travel



⟶ true bearing

1mm : 5 responses

Table 42 Means and standard deviations of error scores

	Same direction as travel						Opposite direction to travel					
	Children			Adults			Children			Adults		
No. of targets away	1	2	3	1	2	3	1	2	3	1	2	3
Mean	11.35	17.85	30.05	5.85	17.80	20.30	19.70	26.15	41.50	10.75	22.05	19.50
Standard Deviation	10.96	19.12	19.90	8.10	14.01	13.72	21.95	18.25	36.24	19.82	16.03	14.76

of travel. Tukey's HSD test showed that the subjects made significantly smaller errors when pointing to targets which are only one location away from the station point than they do when pointing to targets which are two locations away (HSD = 7.49, 36 df, $p < .05$), or to targets which are three locations away (HSD = 9.497, 36 df, $p < .01$) which is to be expected because the targets one location away were in view, whereas those of two or three locations away were not.

Discussion

Firstly, the results suggest that although both adults and children can make crow-flight direction estimates to out-of-sight targets, during the amount of experience with the environment provided by this experiment, the adults were able to show more accurate knowledge than were the children. Of course, this experiment does not provide evidence as to whether, given enough experience with the environment, the children would be able to produce as accurate estimates as the adults, or whether the children could never be able to make as accurate responses. The difference could have been due to the fact that unfortunately the adults had had more previous experience with the experimental environment than the children. The effect of further experience with the environment on the children's knowledge could be tested in an experiment which had further learning and test sessions, but it was not possible to increase the length of the present study as the children were beginning to find it tedious by the fourth session, and would not have cooperated further.

The results of the within- and between-path comparisons suggest that at this stage of learning, both the adults and the children had integrated the two routes into one network. However, because the environment was not entirely novel to the subjects at the beginning of the experiment, it is still possible that the two routes were coded as separate schema at an earlier stage of acquisition.

The results from the 'in direction of travel' and 'opposite to direction of travel' comparisons suggest that, for both adults and children at this stage of acquisition the routes are encoded in terms of sequential associations, as found by Moar and Carleton (1982).

So how do these findings fit Byrne's (1979, 1982) network-map/vector-map theory of spatial representation, to which I have been referring throughout this thesis? The apparent integration of the two route schemas suggests that both the adults and the children have at least network-map knowledge. But is there sufficient evidence to suggest that either or both of the subject groups have vector-map knowledge? The problem is whether the directional knowledge shown by the subjects could have been derived from a network representation, or whether vector knowledge is necessary. If the evidence is examined, one can see that neither adults nor children have a spatial representation which is an exact replica of the real world, as both make errors in their directional estimates, even though they are able to point in roughly the correct direction.

Secondly, both subject groups code the routes sequentially to some extent, and there is an indication, at least, that for the children relative locations are coded in terms of the number of intervening locations, rather than the crow-flight distance. It is therefore possible that the subjects' errors in making direction estimates are because their responses are derived from a form of network representation in which an approximate direction of turn at each location is coded, and distance knowledge is in part derived from the number of nodes between locations. Several authors have found that both adults and children use heuristics and categorization of knowledge when storing small-scale spatial knowledge (for example, Stevens and Coupe 1978; Tversky 1981; Acredolo and Boulter 1984) and similar findings have also been made for large-scale environments. Byrne (1979) found evidence that adult spatial knowledge relies on heuristics such as the more locations remembered on a route, the longer it must be; and junctions and turns are based on a right-angle. Increased experience with an environment may lead to more vector-like representations, perhaps beginning with the network-map being augmented by some true spatial information, and this may well be what has happened for the adults in this study, as their direction estimates became more accurate with experience, and there is some evidence that they were less reliant upon sequential coding than the children. This particular experiment cannot answer whether the children's knowledge would become less reliant on heuristics, and more truly spatial, with additional experience.

Chapter 11

Discussion and Conclusions

A. Methodological considerations

This thesis has shown that it is possible to investigate preschool children's spatial knowledge in natural environments, such as the children's homes (Chapter 6), local outdoor areas (Chapters 5, 6, 9 and 10), and large buildings (Chapters 7 and 8). It therefore supports the recent move towards looking at all children's spatial knowledge and behaviour in environments they encounter in their everyday lives, as opposed to using laboratory based experiments (for example, Cohen *et al*. 1978; Spencer and Darvizeh 1981a; Biel and Torell 1982). Although the use of such test settings imposes the problem of finding suitable existing environments within the locality, it overcomes the difficulty of extrapolating from findings in laboratory settings to the real world. For example, the size of the spatial environment used in many laboratory tasks precludes motor experience with that environment (for example, Coie, Costanzo and Farnill 1973; Smothergill 1973; Borke 1975; Garfin and Pick 1981), or changes the nature of the task because cues can be used from the surrounding room in which the experimental display is placed (for example, Herman and Siegel 1978; Siegel *et al*. 1979; Herman 1980).

Secondly the experiments in this thesis have shown that useful information can be gleaned about young children's spatial knowledge from their direction estimations. Pointing is comprehensible to preschoolers, and requires a minimum amount of equipment which is an advantage when experimentation involves walking around large areas, and adds to the simplicity of the task for the children. Although experimenters using older subjects have found that the combination of distance and direction estimates provide the most information (for example, Siegel 1981), direction estimates only were chosen here because (i) this reduced the danger of demanding too much of each preschool subject, (ii) it is ideal for discriminating competence based on vector-maps from that based on network-maps (Byrne 1979, 1982), or Euclidean from topological representation (Piaget _et al_. 1960; Piaget and Inhelder 1967), and (iii) one cannot trust the reliability and validity of distance estimation tasks with young children.

B. Theoretical Considerations

This thesis has for the first time considered preschool children's spatial abilities in terms of Byrne's (1979, 1982) network-map/vector-map theory of spatial cognition, as well as the more familiar Piagetian distinction between topological and Euclidean spatial thought (Piaget _et al_. 1960; Piaget and Inhelder 1967). Network-map knowledge is topological, consisting of branching networks of strings, each string being a program for action, whose execution would enable travel along a particular route. This analogy with a computer program implies that knowledge would not be reversible, so a route _back_ would entail another string being added to the network. An indication of network-map knowledge was taken to be expressing the direction to a target by pointing along the path one could walk to the target instead of pointing the crow-flight direction. Although similar to Piaget's topological knowledge, network-maps are much more rigidly defined. Vector-maps are Euclidean in nature, and therefore encode knowledge about the distance between locations, and their relative bearings. An expression of vector-map knowledge is the ability to make accurate crow-flight direction estimates to hidden targets. Byrne's (1979, 1982) distinction between network-map knowledge and vector-map knowledge is useful when thinking about children's spatial ability, as well as that of adult's, as it reflects Piaget's differentiation between topological and Euclidean knowledge, without the implication of development through qualitatively different stages. Moreover the use of Piagetiam terminology is embedded within many years of interpretation, a problem which Byrne's network-map/vector-map theory circumvents.

C. Experimental findings and their implications

In the situations tested in this thesis, preschool children aged between two years ten months and five years three months have shown both topological/network-map knowledge and Euclidean/vector-map knowledge. Within the age range tested, there is apparently no time at which the children have network-map knowledge alone. When tested in the home (Chapter 6), where Euclidean/vector-map knowledge was most likely, all of the children gave crow-flight responses above chance level.

This thesis has produced very little evidence to suggest that spatial ability is determined by the age of the child, within the age range tested. The three significant results found for age (Chapters 4, 6 and 9) were as would be expected: that is, the older the child the more accurate responses they make, and the less they rely on network-map knowledge.

Nor does sex seem to be an important factor in determining spatial ability in the real-world tasks used here. The only significant results involving sex (Chapter 8) were part of an interaction and did not clearly suggest a consistent superiority of either boys or girls. The literature about sex differences on spatial tasks has been mixed, some suggesting a male superiority (for example, Lord 1941; Munroe and Munroe 1971; Liben and Golbeck 1980; Spencer and Weetman 1981), whilst others show a general lack of sex differences (for example, Miller 1978; Partridge 1979; Garling, Book and Ergezen 1982), and the occasional female superiority (Bishop and Foulsham 1973). These mixed findings probably result from the variety of tasks used. Only those experiments which use large-scale environments, which have to be built up from successive views, are relevant here. However, even on large scale tasks, whether map drawing or pointing tasks have been used, male superiority has sometimes been found for both adults and children (for example, Anooshian and Young 1981; Spencer and Weetman 1981; Webley 1981), and is sometimes absent (for example, Pearce 1981; Garling _et al_. 1982). There is as yet no apparent explanation for these differing results.

In this thesis, no significant correlations were found between scores on the English Picture Vocabulary test and spatial ability.

This suggests either that spatial representation is not related to intellectual ability within the ability range tested, or else the measure of intellectual capacity used here was not sufficient to reflect spatial abilities. However, a similar lack of relation between intellectual aptitude and level of spatial representation has been found for teenagers (Moore 1974, 1975).

So, if the children's spatial abilities are not related to their age, sex or EPV scores, what does determine the responses they make? This thesis has shown that for preschool children the use of network-map knowledge declines first in environments which are small (Chapters 6, 7 and 8), familiar (Chapters 5 and 6), and actively explored (Chapter 6), and it is these same environments in which vector-map knowledge is most likely. However, the amount of experience with the environment provided by the experiments in this thesis was not always sufficient for the children's direction estimations to become accurate enough to be regarded as vector-map knowledge. These findings are consistent with evidence about adults' spatial abilities from other sources. Adults too are likely to show accurate spatial knowledge in small, over-learned environments, experienced by direct exploration, such as a single floor of an office where one has worked for some while; but they can also build up accurate knowledge of larger places, such as a whole country or town, from maps (Moar 1979). However, adults are unable to build up accurate spatial knowledge in all environments. They show inaccurate knowledge in small but unfamiliar places learned by direct experience, such as one floor of a novel building (Moar 1979); and a specific absence of vector-map knowledge in the presence of good network-map knowledge in some larger environments learned by direct experience, such as a town centre (Byrne 1979). So both adults and children show topological knowledge in some situations, and Euclidean knowledge in others. Both adults and children show network-map knowledge when the qualities of a particular environment and how it is learned make the expression of vector-map knowledge impossible. Young children are probably more restricted than adults in the environments in which they can show vector-map knowledge.

Byrne's (1979, 1982) network-map/vector-map theory implied that network-maps are coded in one direction, the direction of travel, only. For adults, when the environment was presented in the form of a series of slides, Moar and Carleton (1982) have supported this implication, and shown that two separately learned but overlapping routes are encoded as an integrated network. It is possible that these results are an artefact of slide presentation. However, this thesis has tested preschool children in natural environments learned by walking through them, and shown that young children's network-map knowledge is unidirectional (Chapter 9), and that for preschool children also two separately learned but overlapping routes are encoded as an integrated network (Chapter 10).

Some preschool children understand that pointing along the path is not the correct way to make a direction estimate, but are unable to make accurate direction estimates, perhaps reflecting the beginnings of vector-map knowledge. Other preschool children have vector-map knowledge, at least in part, but continue to make path responses, although these responses are not reliant upon the walked route, and reflect the shortest way to walk to the target (Chapter 9). This type of responding implies that the children's 'real' knowledge is interpreted by a rule which says something like 'always point along a path because people cannot walk through buildings etcetera'. It is therefore possible that in previous work children's spatial knowledge has been misinterpreted as inaccurate, when infact they were expressing their Euclidean knowledge by pointing along a walkable path. The distinction between path responses and path bias Euclidean responses can only be made in carefully chosen environments such as in Chapter 9. When children and adults were tested in the same environment, preschool children were unable to express as accurate vector-map knowledge as adults (Chapter 10), although it is possible that given more experience with the environment, the children could have shown as accurate knowledge as the adults.

Although a parallel has been drawn throughout this thesis between Byrne's (1979, 1982) network-map/vector-map dichotomy of spatial knowledge, and Piaget's (Piaget _et al_. 1960; Piaget and Inhelder 1967; Piaget 1977) distinction between topological and Euclidean spatial knowledge, when considering how _development_ of spatial abilities takes place, it is necessary to remember that Piaget spoke about development in terms of stages, and to consider the findings of this thesis in this light. At first sight, this would appear to be an easy task, but a closer inspection of the work of Piaget and those who come after him suggests some confusion over exactly what was meant by 'stages of development'. On some occasions Piaget and his coworkers appear to imply, and have been interpreted as saying, that when children develop from one stage to the next, this change in behaviour is complete and final, and one would not expect to see any occurences of the former behaviour or mode of thinking again. For example, Piaget's first criterion of stages is, 'stages of development are defined by structured wholes and not by any isolated pieces of behaviour. The concrete groupment structure allows not only the solution of particular concrete problems but all the elementary types of classification, arrangement in series, and conservation of number' (Inhelder, 1956 p. 84) and the second criterion, 'the passage from an inferior stage to a superior stage is equivalent to an integration: the inferior becomes part of a superior' (Inhelder 1956 p. 84), but 'to avoid any misunderstanding, it is essential to state that this integrating characteristic does not in itself assume the necessity of finding S1 as such in S2, as though we were in the presence of a model of additive nature' (Pinard and Laurendeau 1969, p. 127). This would suggest that development takes place as shown in Fig. 26, with all thought and behaviour changing from topological to Euclidean at a certain point in time. Indeed, many researchers have interpreted Piaget in this way, and have taken issue with him on finding that even adults are unsuccessful on some Euclidean tasks (for example, Thomas and Jamison 1975; Thomas, Jamison and Hummel 1973; Liben 1978; Newcombe 1982). However, on other occasions Piaget and his coworkers appear to imply that stages have merely a heuristic value of describing the most likely behaviour, for example, 'naturally, during each day the child goes through oscillations of thought, and both the adolescent and the adult are far from reasoning formally all the time. The attainment of a cognitive stage merely means that an individual under optimal conditions becomes capable of behaving in a certain way

Fig. 26 A possible interpretation of Piaget's theory of spatial development

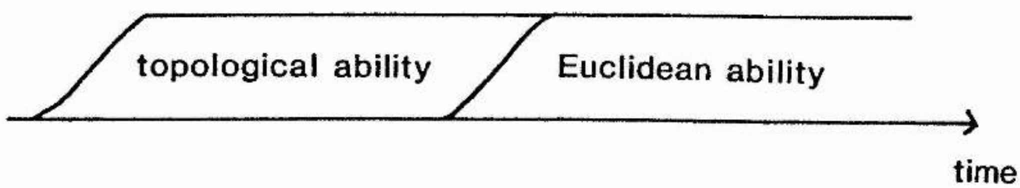
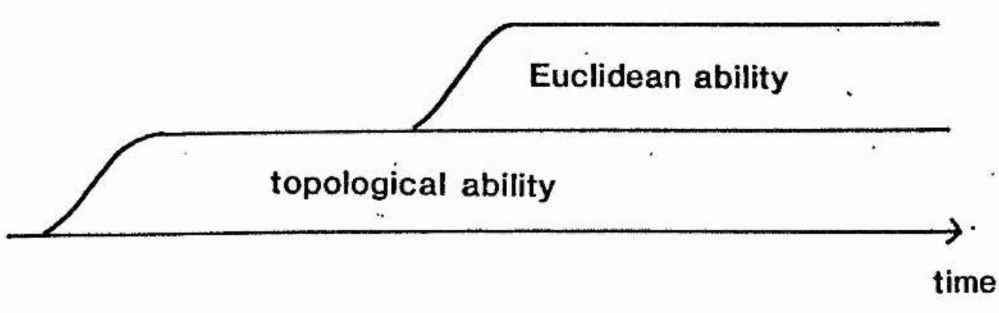


Fig. 27 A second possible interpretation of Piaget's theory of spatial development

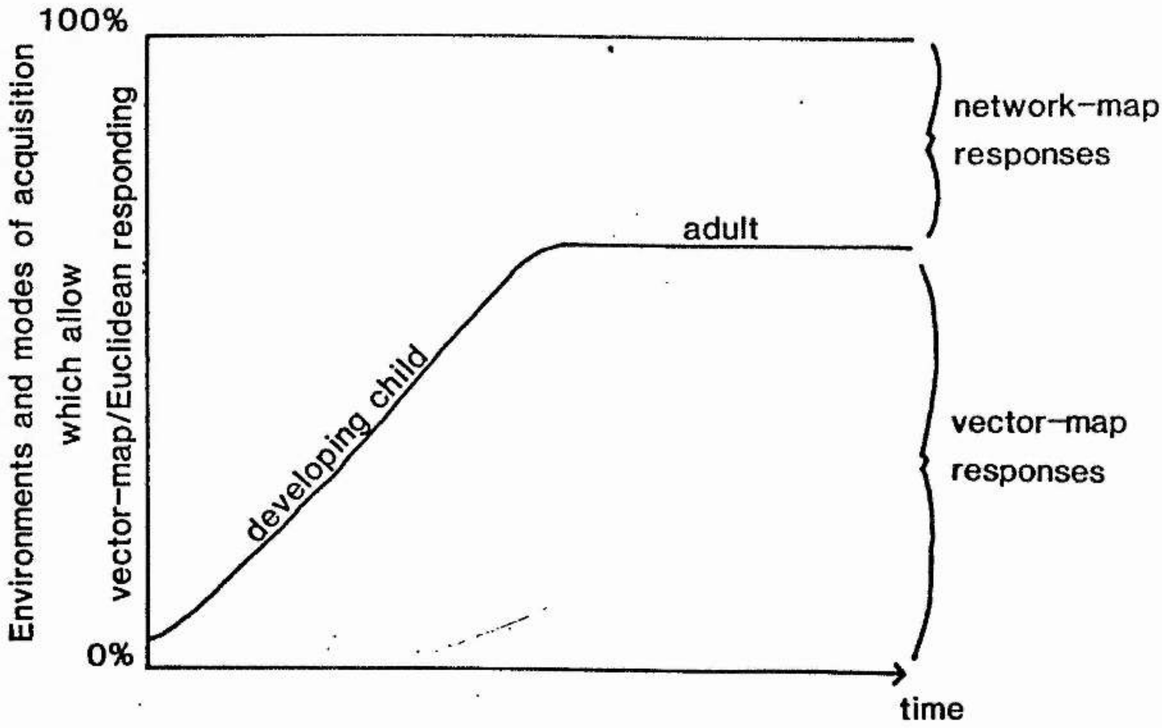


which was impossible for him before' (Inhelder 1960 p. 125-6). In this case, development would take place as shown in Fig. 27. At a certain stage, Euclidean knowledge becomes available to the child, and will be shown where possible, but there is still the possibility that topological knowledge will be expressed in some situations. It implies that there is a stage at which young children have no Euclidean knowledge. Evidence from this thesis suggests that development takes places as shown in Fig. 28. As children grow older, the number of situations in which they can express Euclidean/vector-map knowledge increases, but even adults do not always show such knowledge, and in some situations will rely on topological/network-map knowledge. Of course, this thesis did not test children below two years and ten months of age, so there may be no situations in which younger children are able to build up vector-map knowledge. Nevertheless, if Piaget is taken as suggesting that development happens as in Fig. 26, then the evidence from this thesis contradicts him on two accounts. Firstly, neither adults nor children reach a point at which they express Euclidean knowledge all the time; it is situation dependent. Development therefore does not apparently take place in exclusive and qualitatively different stages. Secondly, Piaget (Piaget et al. 1960; Piaget and Inhelder 1967) suggest that children should not begin to express Euclidean knowledge until at least seven years of age. All the children used as subjects in this thesis were much younger than that, and yet none of them showed exclusive reliance upon topological knowledge, and many had accurate Euclidean knowledge. Although Piaget's ages were only meant as guides or averages, of course, even he would be unlikely to anticipate as much variation as found here, as he tended to play down the fluctuations in age (Piaget 1956). However, if Piaget's theory of development is interpreted as Fig. 27 suggests, then only the second objection to his theory, that of age, stands.

D. Conclusions

Preschool children's spatial abilities can be investigated in natural settings. Contrary to previous expectations (Piaget et al. 1960; Piaget and Inhelder 1967; Siegel and White 1975), such children's spatial knowledge in not merely topological and route-like, nor does it develop through exclusive and qualitatively different stages. Children's spatial abilities can be described in terms of Byrne's (1979, 1982) network-map/vector-map theory, which has some parallels with Piaget's distinction between topological and Euclidean spatial knowledge. Like adults, preschool children's expression of topological/network-map knowledge, and Euclidean/vector-map knowledge is situation dependent. Young children are most likely to express vector-map knowledge in small, familiar and actively explored environments such as the home, then in larger passively explored but familiar environments (such as the area around the home), and lastly in novel environments. Network-map knowledge is coded in one direction only, and two separately learned but overlapping routes are encoded as an integrated network. Some children understand that pointing along the path is not the correct way to make a direction estimate, but are unable to make accurate vector-map responses. Others apparently have Euclidean knowledge, but this is tied to pointing along the nearest path to the target, and previous misinterpretation of this response may have led to an underestimation

Fig. 28 Hypothesized model of spatial development



of children's spatial abilities. In either case, one would expect more accurate vector-map responses with additional experience in that environment and/or development of the child.

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