The role of task variables on young children’s ability to use spatial coordinates

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Abstract

Recent work by Lidster & Bremner (1999) and others (Blades & Spencer, 1989; Lidster, 2002) indicates that young children are capable of both interpreting and constructing Euclidean coordinate references and that differences in performance may exist both between these tasks and within these tasks according to the position of the target relative to the cues to location. This thesis reports a series of experiments that were conducted to explore the basis for these differences and to examine developmental trends in the acquisition of Euclidean coordinate reference systems using analysis of both correct responses and errors made in performing these tasks.

Experiments One to Three examine the effects of scoring criteria, response demands and dimensionality on performance in construction and interpretation tasks amongst three-and-a-half- to six-year-old children. The results suggest that developmental changes in accuracy are present and that response demands and biases may to some degree explain differences in performance between and within tasks. These biases are also age dependent.

Experiments Four to Six further examine the reasons for differences in performance by manipulating factors such as the presence of distracting non-target objects, scale and response characteristics. It was found that when children’s responses are not constrained by the nature of the equipment used in the earlier studies, construction and interpretation of Euclidean coordinates does not occur to the same degree. In contrast, children of this age group appear to favour construction and interpretation of cues to location that are non-Euclidean and show distinctly different responses to those observed in earlier studies giving support to the idea that a true grasp of Euclidean space is not present in early childhood and that young children are highly reliant on some form of perceptual support for correct performance.
The role of task variables on young children's ability to use spatial coordinates

Contents

Abstract ................................................................. ii
Acknowledgements .................................................. iii
Contents ................................................................. iv

PART ONE
Chapter 1: Introduction

Introduction .............................................................. 1

Approaches to the Development of Young Children's Spatial Abilities
Overview ................................................................. 3
Theoretical Perspectives ............................................. 3
The Process of Development ...................................... 19
Mechanisms of Development .................................... 34
Perspective Taking and the Use of Coordinate References ........................................ 40
Aims of the Current Research ................................. 51

PART TWO-Empirical studies

Overview ................................................................. 52

Chapter 2: Study One
Comparison of performance on simultaneous versus serial construction task.
Introduction .............................................................. 54
Method ................................................................. 59
Results ................................................................. 63
Discussion ............................................................... 68
Chapter 3: Study Two
Age effects on the interpretation of coordinate dimensions.

Introduction ...........................................................................  71
Method .............................................................................................73
Results ...............................................................................................75
Discussion ..........................................................................................79

Chapter 4: Study Three
The effect of 2-dimensional and 3-dimensional materials on performance in a spatial interpretation task

Introduction ..........................................................................................81
Method .................................................................................................85
Results .................................................................................................88
Discussion ..............................................................................................94

Comparison between Study Three and Study Two
Results .................................................................................................96
Discussion ..............................................................................................98

Comparison between Study Three and Study One
Results .................................................................................................98
Discussion ..............................................................................................100
Summary .................................................................................................101

Chapter 5: Study 4
The effect of removal of distractor items on children’s ability to perform construction and interpretation tasks involving spatial coordinates.

Introduction ..........................................................................................103
Method .................................................................................................105
Results .................................................................................................108
Discussion ..............................................................................................115
Chapter 6: Study 5
The effect of scale on young children’s ability to use coordinate dimensions.

Introduction .................................................................................................................119
Method ........................................................................................................................122
Results .........................................................................................................................125
Discussion ...................................................................................................................138

Chapter 7: Study 6
Young children’s ability to use spatial coordinates on a touch screen

Introduction .................................................................................................................142
Method ........................................................................................................................146
Results .........................................................................................................................149
Discussion ...................................................................................................................155

Chapter 8: General Discussion
Overview .....................................................................................................................158
Summary of Results ....................................................................................................158
Factors affecting young children’s use of spatial coordinates ..................................163
Directions for future research .....................................................................................168
Conclusion ..................................................................................................................169

References .....................................................................................................................171

Appendix 1 ...................................................................................................................214
Appendix 2 ...................................................................................................................215
Appendix 3 ...................................................................................................................216
ILLUSTRATIONS

1. LIST OF FIGURES

2.1 Position of imaginary lines dividing area into six by six grid 58
2.2 Apparatus used in current study 60
2.3 Different trial types- target position shown in black 61
2.4 Mean number of correct responses by two age groups using two scoring criteria 65
2.5a Mean number of correct responses according to position pointer using Absolute Accuracy scoring criteria 66
2.5b Mean number of correct responses according to pointer position using Correct Quadrant scoring criteria 66
2.6 Frequency of each type of error for all trials by condition 68
3.1 Mean number of correct responses by trial type and age group 76
3.2 Frequency of different error types made by children on coordinate interpretation task 77
4.1 Apparatus used in the two-dimensional condition 86
4.2 Apparatus used in the three-dimensional condition 86
4.3a Mean scores by trial type under correct Quadrant scoring criteria 90
4.3b Mean scores (out of four) by trial type, under Absolute Accuracy scoring criteria 91
4.4 Mean number of correct responses by scoring criteria and age 91
4.5 Frequency of different error types by trial type 92
4.6a Frequency of three error types by condition amongst children younger than five years old. 93
4.6b Frequency of three error types by condition amongst children older than five years old. 93
5.1 Mean number of correct responses out of sixteen for two age groups using two scoring criteria 110
5.2a Mean number of correct response for each trial type using the Correct Quadrant criterion 112
5.2b Mean number of correct responses for each trial type using Absolute Accuracy criterion 112
5.3 Mean number of correct responses in construction and interpretation conditions using two scoring criteria

5.4a Mean number of correct responses in first and second tasks under different task orders according to Correct Quadrant scoring criterion

5.4b Mean number of correct responses in first and second tasks under different task orders according to Absolute Accuracy criterion

5.5 Example of type of error, placing cup next to marker on interpretation condition

5.6 Example of type of error, placing cup on imaginary line between two pointers

6.1 Comparison of equipment used in Study Four and Study Five

6.2a and b Mean number of correct responses for each trial type on construction and interpretation tasks using the Correct Quadrant criterion

6.3a and b Mean number of correct responses for each trial type on construction and interpretation tasks using the absolute Accuracy criterion

6.4 Mean number of correct responses in first and second tasks under different task orders according to Absolute Accuracy criterion

6.5 Mean number of correct responses in first and second tasks under different task orders according to Correct Quadrant criterion

6.6 Mean scores in first task by trial type and task order according to correct quadrant criterion

6.7 Mean scores in first task by trial type and task order according to absolute accuracy criterion

6.8 Mean scores in second task by trial type and task order according to correct quadrant criterion

6.9 Mean scores in second task by trial type and task order according to absolute accuracy criterion

6.10a and b Mean number of correct scores for each trial type according to two scoring criteria

6.11 Mean number of correct responses in first and second tasks by condition

6.12 Mean number of correct responses for first and second tasks by condition

6.13 Mean scores for different trial types by study

6.14 Mean number of correct responses by trial type in two age groups

7.1. Touch screen showing interpretation trial
7.2 Position of touch screen and Notepad relative to child. 149
7.3 Mean number of correct responses on interpretation task by trial type and age 152
7.4 Mean scores by trial type and age 153
7.5 Mean total scores for older and younger children in Studies 2 and 6 (Standard vs. touch screen tasks) 153
2. LIST OF TABLES

2.1 Study One: Mean scores by trial type according two scoring criteria 63
3.1 Study Two: Mean number of correct responses by trial type 75
3.2 Study Two: Mean scores by trial type for interpretation task and simultaneous construction task 78
4.1 Study Three: Mean number of correct responses by trial type, condition and scoring criterion 89
4.2 Study Three: Mean scores by trial type and data set 97
4.3 Study Three: Mean scores by trial type on construction and interpretation tasks according to two scoring criteria 99
5.1 Study Four: Mean scores by trial type according to two scoring criteria 109
6.1 Study Five: Mean scores by trial type according to two scoring criteria 126
6.2 Study Five: Mean scores by trial type according to two scoring criteria 132
7.1 Percentage of children by trial type scoring correctly on both trials of the interpretation task. 150
7.2 Percentage of correct responses on an interpretation task by trial type under touch screen and standard conditions 151
7.3 Frequency of different response types in serial and simultaneous conditions of the construction task 155
Introduction

An increasing ability with age to understand space, and interact with objects within space, is basic to children’s cognitive development and an understanding of spatial location is vital to interacting and functioning within the environment. Piaget’s theory of spatial development (Piaget & Inhelder, 1956) aims to trace the pattern of spatial development from birth through to maturity and suggests that children’s spatial abilities progress through three stages: Topological, Projective and Euclidean.

According to Piaget & Inhelder (1956), children’s early spatial representation is in the form of limited topological knowledge based on proximity to and contact with other objects. Knowledge regarding the location of objects is coded relative to one another and also one’s own position. Later, projective representation allows for knowledge, albeit incomplete, of perspectives and the relationship between different views. Only in the Euclidean stage do Piaget & Inhelder (1956) suggest that the child can fully coordinate perspectives, coordinate both metric and distance information and mentally manipulate space with reference to a system of Euclidean coordinates.

The picture Piaget & Inhelder (1956) present is of a spatially (and cognitively) incompetent young child, lacking true object permanence until around the age of one; spatially and cognitively egocentric until the age of seven and unable to grasp concepts of Euclidean space until the age of eleven. However, recent research has suggested that the young child is more spatially competent than Piagetian theory proposes. Object permanence, in the form of shape and size constancy has been observed in young children below the age of one (Slater, Morison & Somers, 1988; Slater, Mattock & Brown, 1990). Young children have also been shown to have much more sophisticated spatial abilities than those proposed by Piaget & Inhelder (1956), showing an ability to code location metrically and categorically (Huttenlocher, Newcombe & Sandberg, 1994; Newcombe & Huttenlocher, 2000) and to appreciate others’ perspectives (Lempers, Flavell & Flavell, 1977). In addition there is substantial evidence to suggest that children well below the age postulated by Piaget & Inhelder (1956) are able to construct and interpret coordinate references as cues to location (Blades & Spencer, 1989; Lidster & Bremner, 1999).
Overall, these findings support the idea that young children are substantially more spatially competent than proposed by Piagetian theory, although the degree of competence displayed depends to a large extent on methodological and situational factors. It could be argued that, where tasks are designed to be ‘child friendly’, these could be accused of overestimating young children’s spatial abilities to the same extent that other tasks have been accused of underestimating them.

With a view to extending our current understanding of young children’s spatial abilities, the following research aims to examine the ability to use coordinate dimensions in spatial tasks, both in terms of constructing and interpreting cues to location. In particular this research aims to investigate factors leading to success and failure on these tasks and accuracy on these tasks, building on the findings of Lidster (2000), Lidster & Bremner (1999) and others.

Part One reviews the existing literature related to young children’s spatial development with particular focus on perspective taking and the use of coordinate references whereas Part Two reports a series of six associated studies aimed at addressing some of the issues raised by existing research into young children’s interpretation and construction of coordinate references and discusses the findings of these studies. Finally Part Three forms a general discussion of the results of the series of studies as a whole with consideration of the findings within the broader context of theories regarding young children’s spatial development. In addition future directions for research are suggested.
Chapter 1:  
Approaches to the Development of Young Children’s Spatial Abilities

Overview

The present chapter aims to provide an account of the theoretical and empirical background to the research reported in this thesis. First, the chapter will outline the main theoretical approaches to human cognitive development, those of the empiricists, the nativists and interactionists, and discuss evidence for each of these viewpoints with regard to young children’s early spatial abilities. Second, this chapter will outline the process of the development from birth of spatial knowledge and introduce theories relating to the mechanisms of development. Finally, this chapter will focus on issues specific to children’s perspective-taking ability and the use of coordinate dimensions, focusing on the debate concerning whether young children have an understanding of Euclidean space and are able to use coordinate reference systems. Evidence suggesting children are capable of using Euclidean coordinate references at an early age will be presented as well as discussion of conditions affecting performance. This last element for discussion leads into the aims of the present research.

Theoretical perspectives

Current research on spatial abilities and their development is embedded in general theories of cognitive development. Theorists differ in both their assessment of early capabilities and the nature and process of change throughout development. Theoretical approaches to the development of spatial abilities include the Piagetian approach (Piaget & Inhelder, 1956), the nativist approach supported by researchers such as Spelke & Newport (1998) and the work of researchers including Huttenlocher and Newcombe who suggest that whereas infants may be born with considerable spatial abilities, these abilities undergo adaptive change through experience (e.g.

The Piagetian Approach

Piaget’s approach to cognitive development is essentially empiricist. Piaget & Inhelder (1956) state that the perception of space involves a gradual construction and that it does not exist at the outset of mental development. The construction of space, like all other aspects of cognitive development proceeds through interaction with and adaptation to the environment. Piaget identifies different stages of cognitive development which determine children’s performance on a variety of tasks (Piaget & Inhelder, 1969). He contends that these stages are universal across the normal population and that movement through these stages is fixed in terms of order and to a lesser extent age. Piaget’s suggestion is that during each of these four stages of development (sensori-motor, 0-2 years; pre-operational, 2-7 years; concrete operational, 7-11 years and formal operational, 11+ years) the same principles guide the child’s reasoning regardless of the area to which it is applied, moreover, changes occur more or less simultaneously across different domains reflecting domain-general changes in representational structures. In this regard he views cognitive development as domain general.

According to Piaget (1953), the child develops ways of interacting with the world around them through processes of adaptation, assimilation and accommodation. Infants initially have few ways of interacting with their environment (schemata). Early schemata may include grasping and sucking reflexes. Adaptation occurs when the infant in some way modifies their actions to the environment around them. This in turn may result in new forms of information being incorporated into the schemata (assimilation) and the schemata being adjusted or updated to allow for this new information (accommodation). According to Piaget’s theory, accommodation occurs because disequilibrium, which is an undesirable state, occurs if existing schemata cannot cope with the newly assimilated information (Piaget 1953). By adjusting existing schemata through a process of accommodation, equilibrium is restored.

Piaget’s stages of development, being domain general, affect all aspects of the child’s knowledge and represent a progression from concrete to abstract thought, from
fusion to differentiation and from egocentrism to perspectivism (Hart & Moore, 1973). During the sensori-motor stage the child is said to be pre-representational, having no internal representations or concepts. During this period their conception of objects and space is limited to their own actions and perceptions (Piaget, 1954).

Gradually representational thought emerges and with this object permanence, the knowledge that objects exist in space even when they are not directly perceived. According to Piaget this object permanence becomes fully developed between the ages of eight months to one year, at which time A-not-B search errors cease to occur.

By the end of the child’s second year the child progresses to the pre-operational stage. During this stage which lasts until approximately seven years of age, the child’s constructs are largely based upon their own personal experiences and they initially lack the ability to decenter from these (egocentrism). Spatial relationships are defined in terms of topological cues such as proximity and touchingness. As the child progresses through the pre-operational and concrete operational stages to the formal operational stage, egocentrism and the reliance on proximal cues are gradually replaced by an understanding of projective and Euclidean spatial relationships as well as the development of logical thought. Projective spatial coding enables children to be aware of location in terms of lines of projection from a point in space and is typified by a limited degree of knowledge of different perspectives and children are aware that differing viewpoints will result in differing views.

During the Concrete Operational stage children are capable of logical abstraction although there is still a reliance on concrete experience. The child is able to coordinate perspectives although may rely on visual materials to aid them. Projective and Euclidean spatial coding develops more fully during the concrete operational stage until, finally, during the formal operational stage (after the age of about eleven), the child at last develops the level of reasoning and logical thought that is present in adults. The child is able to reason in the abstract without a reliance on concrete materials as an aid. The child’s intellectual functioning is symbolic and they are able to construct testable theories about the world, can also reason about space in an abstract fashion and mentally manipulate objects in space (Piaget, 1954).

With regard to spatial knowledge in particular, Piaget’s theory, as stated above, suggests that at birth infants are without knowledge of space or a conception of permanent objects that occupy space. Piaget & Inhelder (1956) suggest that a child progresses through qualitatively different stages in terms of their thinking about
spatial relationships. Initially the infant has no internal representation of space. The earliest stage of representational thought is Topological, in which location is coded in terms of continuities and discontinuities such as touchingness, separation, proximity, order and enclosure. According to Piaget & Inhelder (1956) this early form of representational thought ignores metric and perspective relationships and coordinate systems or horizontal – vertical relationships are only fully developed by the age of eight or nine. Later stages of spatial thinking are the Projective stage, which emerges during the concrete operational stage of development and involves knowledge of the relationships between several objects, perspective and the relationship of other views. Finally, the Euclidean stage is reached, which coincides with formal operational thought, when the child is able to fully coordinate perspectives and recognize relationships and properties in metric terms. This Euclidean coding allows a point in space to be defined independently of objects and objects to be manipulated mentally through more than one dimension. Although there is some ambiguity in their writings (Newcombe 1989), Piaget & Inhelder (1956) see Projective and Euclidean coding as conceptually intertwined and emerging side by side but Euclidean coding does not appear in its mature form until later on in development.

However, despite Piaget’s assertion that mature spatial coding does not begin to develop until middle childhood and is not fully developed until early adolescence, this does not imply that there is no metric or projective coding in early childhood. As Piaget & Inhelder (1956) remark when referring to the emergence of size and shape constancy in the first year of life:

'to perceive the true dimensions of an object at a distance involves reconstructing constant size (and thus metric) from a figure diminished by perspective (and thus projective shape), consequently uniting in one whole both projective and Euclidean vision. It would appear that both projective and metrical relationships are developed jointly and are interdependent.' (Page 11)

Piaget and Inhelder’s viewpoint suggests that mistakes children make during spatial tasks are indicative of immature spatial concepts. Classically error-prone Piagetian spatial tasks are those such as the A-not-B search paradigm in infancy (Acredolo & Evans, 1982; Bremner, 1978a, 1978b; Bremner & Bryant, 1977; Piaget, 1954), the three mountains task, the model village task, the water level task and tasks requiring children to recreate a point in space along two and three dimensions (Piaget & Inhelder, 1956). These tasks have shown that young children’s performance differs
from that of older children and mature adults (Carlson, 1976; Piaget & Inhelder, 1956; Piaget, Inhelder & Szeminska, 1967) suggesting there is a qualitative developmental shift in spatial representation. Further support for this Piagetian stance comes from work on young children’s use of maps by Downs, Liben and colleagues, (Downs & Liben, 1987; Downs, Liben & Daggs, 1988; Liben 1991; Liben & Downs, 1989) who argue that young children are unable to handle the basic operations involved in map use and in particular have an inferior understanding of perspective, scale and symbolism. It has however been noted that even the ‘mature’ systems of adults, spatial distortions and inconsistencies occur in a fashion that indicates that mature methods of spatial representation are not purely Euclidean (Byrne, 1979; Hirtle & Jonides, 1985; Kuipers, 1982; McNamara, 1991; McNamara & Diwadkar, 1997).

The Nativist approach

Piaget’s view of cognitive development stresses the role of interaction with the environment for the development of cognitive abilities. However his views have been challenged by those researchers who claim, in contrast, that human infants possess an innate core knowledge which is both domain and task specific (Spelke, 1994), especially with regard to spatial and quantitative concepts (Blaut 1987, 1997; Blaut, McCleary & Blaut, 1970; Landau, Spelke & Gleitman, 1984). Studies of hippocampal and cortical features in rats have suggested a predisposition for a Euclidean framework (O’Keefe & Nadel, 1978), location appears to be coded in terms of distance and direction and is coded independently of changes in the animal’s position. Specific systems for the detection of particular spatial features and locations also seem to exist (Hubel & Wiesel, 1959; McNaughton, Leonard & Chen 1989; Muller, & Kubie, 1987; O’Keefe & Speakman, 1987). The evidence for innate core knowledge concerning space has been suggested through research investigating early competence, by research findings that suggest experience is not essential for cognitive development and by the suggestion that infants come equipped with domain-specific modules.

Early competence

Evidence for innate spatial abilities, supporting the nativist approach can, to some degree, be found by studying children’s early spatial competence. The degree to which children are spatially competent at or shortly after birth, when they have little-
or no visual spatial experience provides an insight into what aspects of spatial abilities are not dependent upon visual experience for development.

There is a large body of research evidence to suggest that Piaget vastly underestimated young children's cognitive and spatial capabilities. Studies of very young infants' perceptual abilities suggest that shape constancy (Bower, 1966; Caron, Caron & Carlson, 1979; Day & McKenzie, 1973; Slater & Morison, 1985; Slater, Morison & Somers, 1988), size constancy (Bower, 1964; McKenzie, Tootell & Day, 1980; Slater, Mattock & Brown, 1990) and knowledge of spatial rules such as the principles of solidarity and continuity (Baillargeon, 1987; Baillargeon, Spelke & Wasserman, 1985; Wang, Baillargeon & Brueckner, 2004) are present at an early age, well before Piaget's lower limit for the onset of object permanence although they may not be fully developed (McKenzie et al., 1980).

Young infants frequently fail to search the correct location for an object that they have seen hidden and have retrieved at location A when it is subsequently hidden in their view at location B (Appel, 1971; Bower & Paterson, 1972; Evans & Gratch, 1972; Gratch, 1974; Gratch & Landers, 1971). This phenomenon is known as the A-not-B error or the AB search error. The absence of searching for hidden or partially hidden objects in infants below the age of approximately eight months and searching errors between the ages of eight and twelve months using the A-not-B search paradigm has been taken as an indication of young infants' lack of true object permanence and their reliance on an egocentric reference system for coding space. Young infants before the age of approximately eight months fail to search for a hidden object even when they have seen it hidden or if it is partially showing.

However there is some suggestion that this failure to search is due to a lack of ability to search in the correct location rather than a lack of object permanence. Studies which gauge infants' expectations through looking-time support this idea. Baillargeon (1986) showed that when infants aged six to eight months were habituated to an event in which a car rolled down a track behind a screen they showed increased looking when the car appeared to roll through a block which had been placed on the track behind the screen, suggesting they had knowledge of the block's presence despite being unable to see it. Similar expectancy violations were found when an object was hidden behind one of two screens and retrieved from the wrong location (Baillargeon et al., 1989; Baillargeon & Graber, 1988; Baillargeon, Graber, De Vos & Black, 1990) Young infants have also been shown to continue to reach for
an object some time after the object has ceased to be in view when lights are turned out (Bower & Wishart, 1972; Hood & Willatts, 1986).

Piaget (1954) suggests that A-not-B errors are due to the object’s identity being intrinsically bound up in their own sensori-motor experience of reaching for it. This idea is supported by Bower & Paterson (1972) who suggest there is evidence for the development of object concept up to the age of eighteen months and that this development is stage-like, as Piaget suggests, rather than continuous. They argue that children below sixteen weeks of age have an object concept that does not differentiate between place and movement (Bower & Paterson, 1973). Evans & Gratch, (1972) on the other hand suggest that A-not-B errors are the result of place going errors rather than errors of object concept. They found that the likelihood of A-not-B errors increases following time delays. Furthermore, Bjork & Cummings (1984) suggest that the A-not-B search error is an artefact of a two-choice task. They found that these errors did not occur when infants were given a choice of five possible locations to search for the object. Bremmer & Bryant (1977) showed that these errors persist when the child is moved around the array, suggesting that egocentric coding is the basis for searching even when the two locations are clearly differentiated in terms of allocentric cues. However Bremner (1978) and Bremner & Bryant (2001) state that when the cues to location are more salient and are stable then infants select the correct location and are not reliant on egocentric coding. This was supported by Acredolo & Evans (1980) who suggest that even six-month-old children show some consideration of landmarks when they are particularly salient.

It is thought that A-not-B errors may in part be due to the initial motor reaching behaviour having been to some degree reinforced (Smith et al., 1995; Smith, Thelen, Titzer & McClin, 1999). Meta-analysis of research suggests that a large numbers of A trials have been shown to increase the frequency of error in AB studies (Marcovitch & Zelazo, 1999) and may also provide opportunities for reflection on the task structure (Marcovitch, Zelazo & Schmuckler, 2002). McDonough (1999) showed that seven-month-old infants were able to remember which of two distinctive containers an object was in after a minute’s distraction when they had no experience of reaching to the containers. These results are supported by the findings of Bremner (1978) who found that infants were capable of using allocentric coding if the spatial relationship between themselves and the object is changed prior to them reaching for it.
Studies of infants' gaze in the A-not-B paradigm suggest that children as young as seven months old direct their gaze at the correct location (Hofstadter & Reznick, 1996) and that infants show signs of expectation violation if an object seen hidden at B appeared at A (Ahmed & Ruffman, 1998). Wellman, Cross & Barisch (1978), in a review of studies of infant searching behaviours, suggest that age, time delay and number of hiding locations all influence the accuracy of infant searching. Cue based coding of location has been further demonstrated in young infants below eight months of age (Rieser, 1979) suggesting that they are not completely reliant on, but are dominated by, a system of coding in terms of their own actions upon those objects.

In addition to evidence of early ability to code the location of objects in a non-egocentric fashion, there is evidence that infants are able to code space metrically to some extent (Bushnell, Mckenzie, Lawrence & Connell, 1995; Huttenlocher, Newcombe and Sandberg 1994; Newcombe, Huttenlocher & Learmonth, 1999). Baillargeon (1987) found that five-and-a-half month old infants showed an expectation violation response when a short rabbit who should not have been visible behind a window was visible and Newcombe et al. (1999) found that five month old infants were able to distinguish between two locations at different points along the length of a sandbox. Bushnell et al. (1995) suggest that one-year-old infants are capable of coding distance and direction from themselves but not from another object.

The presence of these early abilities contrasts greatly with those proposed by Piagetian theory. However it is possible that even very early abilities have developed through experience and interaction with the environment. In addition, there is substantial evidence for development throughout childhood in many of these early abilities. Although infants and young children show considerable competence in some areas compared to that predicted by Piaget’s viewpoint, it should be noted that levels of competence in young children are seldom, if ever on a par with those of adults or even older children.

Modularity

The presence of a domain specific spatial module which governs performance on spatial tasks can be taken as further evidence for genetically programmed, innate spatial abilities. Whereas Piagetian theory suggests that there are relatively few domain-general abilities available at birth, others, such as Karmiloff-Smith (1992)
suggest that infants already have or rapidly acquire domain specific principles which guide and constrain their responses. Karmiloff-Smith argues that although cognitive processes may be molar at birth, they differentiate into distinct modular units as development proceeds.

Alternatively, Fodor (1983), building upon the earlier work of Gall, proposes that the ‘architecture’ of the mind consists of separately functioning and genetically specified ‘modules’. Fodor (1983) proposed characteristics essential for a module, which he defines as

“an informationally encapsulated computational system - an inference-making mechanism whose access to background information is constrained by general features of cognitive architecture, hence relatively rigidly and relatively permanently constrained” (Fodor, 1983, pp200-201)

One of these characteristics is impenetrability or resistance to modification meaning that information from other processes or modules has no effect upon it. Only information from lower stages of processing is available. Hence in the case of illusions such as the Muller-Lyer illusion, despite the knowledge that both lines are of equal length, our perception of the illusion remains unaltered.

However, Karmiloff-Smith (1992) points out that a strict viewpoint of modularity does not allow for the plasticity of the human brain that is often apparent in situations of early brain damage or sensory deficit. Many researchers, whilst emphasising core knowledge have suggested that developmental change does occur (Hermer & Spelke, 1994, 1996; Spelke & Newport, 1998) either as the result of the emergence of modules (Leslie, 1987), increasing modularisation through interaction with the internal and external environment (Karmiloff-Smith, 1992) or of linkage of initially separate modules (Hermer & Spelke, 1996).

Hermer & Spelke (1996) propose the existence of a geometric spatial module. Evidence suggests early competence at using geometric information and that this is used in preference to and ignoring other cues. Hermer & Spelke (1996) suggest their results are due to an informationally encapsulated and task specific mechanism. However Learmonth, Newcombe & Huttenlocher (2001) cast doubt on the notion of the geometric module as cognitively impenetrable. Whereas Hermer-Vazquez, Moffet and Munkholm (2001) suggest that the constraints of the geometric module are only overcome with children’s ability to produce accurately verbal representations of location at around the age of six, their data suggests that toddlers were able to use
landmarks rather than geometry and the key to landmark use appears to be room size. Modularity is only supported in studies using small room sizes (Learmonth, Nadel & Newcombe, 2002). However evidence suggests that the use of geometric information is limited to surrounding environments in younger children and that use of geometric and local cues emerges later in model environments (Gouteux, Vauclair & Thinus-Blanc, 2001).

Modularity theory also proposes that modules are task specific and independent. There is evidence for modularity in the patterns of specific deficits encountered in some children such as deficits in theory of mind amongst autistic children (Frith, 1989) and specific number, spatial and problem deficits in children with Williams Syndrome (Karmiloff-Smith, Bellugi, Klima, Grant & Baron-Cohen, 1995). However, Karmiloff-Smith & Thomas (2003) suggest that these deficits may be the result of constraints upon the plasticity of development through modularisation rather than the product of pre-specified modules in the infant brain. High-level abilities in a single domain are also evident amongst so-called ‘idiots-savants’.

Wynn (1998) proposes that there is an inherent mechanism in the human mind for reasoning with and representing number. There is a wide body of evidence including studies of expectancy violation that suggests sensitivity to number is present at an early age (Antell & Keating, 1983; Simon, Hespos & Rochet, 1995; Starkey & Cooper, 1980; Strauss & Curtiss, 1981; Van Loosbroek & Mitsman, 1990; Wynn, 1992). There is however evidence to suggest that there is a shared basis between spatial and numerical ability. Newcombe et al. (1999) suggest that the five month olds in their sandbox studies are able to code spatial extent. They found that infants showed increased looking time when an object was dug out of a sandbox at a different location to where it was hidden compared to when it was dug out from the same location. Even when the gap was as little as eight inches and both locations were relatively central within the sandbox.

Sensitivity to amount could be common ground for both quantitative and spatial development and differentiation between these domains might be a later development. Research by Gao, Levine & Huttenlocher (2000) suggests that the spatial and quantitative domains may be linked. Spelke & Dehaene (1999) suggest that mechanisms for numerical and spatial processing might be linked within the parietal lobe. Feigneson, Dehaene & Spelke (2004) suggest that two quantification systems exist, one for representing large approximate numerical magnitudes and a
second dealing with the precise representation of small numbers of individual objects. Lange-Kuttner & Friederici (2000) suggest that there are separate modules for object and place memory in children.

There is evidence to suggest that spatial abilities may be modular in nature (Karmiloff-Smith et al., 1993) and some researchers suggest spatial ability forms a crystallised component of overall intelligence which is resistant to environmental influence. Indeed many measures of intelligence include separate subtests for spatial abilities. However the existence of modules does not preclude developmental changes in the functioning of these modules through interaction with the environment.

The interactionist stance

Research seems to favour neither the purely empiricist nor the purely nativist viewpoint. It would seem with respect to the Piagetian approach that the young child is certainly capable of much more than Piaget originally postulated, showing less egocentrism (Flavell, Omanson & Latham, 1978; Newcombe & Huttenlocher, 1992; Yaniv & Schatz, 1990), greater knowledge of metric distance (Bartsch & Wellman, 1998; Fabricus & Wellman, 1991; Miller & Baillargeon, 1990) and less reliance on topological cues to location (Acredolo, Pick & Olsen, 1975; Herman & Siegel, 1978; Huttenlocher & Newcombe, 1984) than proposed. However it would be unrealistic in the light of a wide body of evidence otherwise to propose that the early spatial competence of the child is equal to that of adults (although maybe not as unequal as some propose) or that experience has no bearing on development.

Newcombe & Huttenlocher (1992) showed that although young children between 3 and 5 years old can answer some kinds of perspective taking questions, such as picking out which object is in a particular position in relation to a hypothetical observer (see also Huttenlocher & Presson, 1979), children cannot pick out a picture showing another’s viewpoint until the age of nine or ten. Similarly although infants and young children can code extent to a greater degree than that proposed by Piaget, they are unable to use distal landmarks as cues to location before the age of twenty-one months and this ability develops up to the age of six or seven (Newcombe, Huttenlocher, Drummey & Wiley, 1998; Overman, Pate, Moore & Peuster, 1996).

This fundamental developmental change in spatial ability is also found in rats (Nadel, 1990) and may be the result of hippocampal maturation. O'Keefe, Nadel, Keightley & Kill (1975) found that hippocampal lesions disrupt place learning but not
cue-learning in rats and there is evidence for ‘place cells’ in the hippocampus (Ekstrom, Kahana, Caplan, Fields, Isham, Newman & Fried, 2003; Muller & Kubie, 1987; O’Keefe & Speakman, 1987; O’Keefe & Nadel, 1978). These hippocampal cells may be viewpoint independent (King, Burgess, Hartley, Vargha-Khadem & O’Keefe, 2002).

However, late emergence of some abilities does not necessarily contradict the nativist perspective as later abilities could develop as a result of maturation rather than experience. Such changes have been explained in terms of the emergence or linking together of innate modules (Hermer & Spelke, 1996). It is equally possible that differences in performance between young children and older ones are not as a result of different levels of underlying cognitive abilities but rather the result of differences in learnt strategies (Newcombe & Huttenlocher, 1992). However Newcombe (2002) argues that

‘abilities that take time to emerge are far from trivial in terms of functional significance. It is odd to dismiss as uninteresting the kind of development that takes a nascent ability manifest in only a very restrictive set of circumstances to a mature ability that allows for actual accomplishment’ (page 398)

The interactionist framework as proposed by Newcombe & Huttenlocher (2000) and Karmiloff-Smith (1992) recognizes that newborns may possess relatively sophisticated mechanisms for processing information from the world around them but that these abilities show developmental change and transition as a function of the infant’s interaction with the physical and cultural world.

Environmental input

The role of environmental input allows us to assess to what degree spatial development is a maturational process and to what degree spatial development occurs as a result of interaction with the environment. If experience has a great influence on development then one would expect that differences in environmental experience would have different developmental outcomes.

Much recent research suggests that environmental input is essential to spatial development and that differences in both motor experience and sensory experience can shape spatial abilities (Huttenlocher, Levine & Vevea, 1998). For example, Campos, Anderson, Barbu-Roth, Hubbard, Hertenstein & Witherington (2000) suggest that crawling experience has an established role in transitions in spatial
coding as well as in changes in social and emotional development and there is a wide body of evidence suggesting that locomotor experience has an effect on young children's use of different spatial coding systems (Acredolo, Adams & Goodwyn, 1984; Horobin & Acredolo, 1986; Kermoian & Campos, 1988; Newcombe & Huttenlocher, 2000).

Similarly, the role of visual experience has also been investigated. If visual input were important for the development of spatial knowledge, as empiricists would suggest, then we would expect the abilities of those who have had restricted visual experience to show poorer spatial abilities. Although many researchers would argue that there is considerable evidence for spatial representation in the congenitally visually deprived, Rieser, Lockman & Pick (1980) found that individuals who become blind after having had some visual experience perform better at distance judgements than congenitally blind individuals. Maurer, Lewis, Brent & Levin (1999) studied children with congenital cataracts whose operations to remove these were done at different ages between one week and nine months old and found that visual acuity improved in the month after treatment, with some improvement occurring as little as one hour after treatment. They concluded that patterned visual input was crucial to the development of normal visual acuity. Results suggest that early locomotor and visual experiences are important for spatial functioning.

The role of locomotion

According to Piagetian theory, a child's sensorimotor experience and interaction with the environment has a key role in their cognitive development, therefore locomotor experience should play an important role in the development of spatial abilities. Newcombe & Huttenlocher (2000) state that it is not by coincidence that children show a shift from self-referent modes of coding location to allocentric codes at around the same time that locomotion occurs. They propose that until this point a purely egocentric method of coding is adequate, indeed it constitutes the most effective method of locating an object. Acredolo (1990) suggests that self-produced locomotion is one of the most important milestones of development and Campos, Anderson, Barbu-Roth, Hubbard, Hertenstein & Witherington (2000) suggest that locomotor experience is a crucial agent of perceptual, spatial, emotional and social developmental change but is neither necessary nor sufficient for this change.
Early animal and human studies have suggested that locomotor experience influences such phenomena as fear of heights and depth perception (Campos, Bertenthal & Kermoian, 1992; Held & Hein, 1963) and that locomotor infants show different patterns of attention to objects in far space to prelocomotor infants (Freedman, 1992, cited in Campos et al., 2000). Horobin & Acredolo (1986) found that infants who had experience of self produced locomotion were more likely to search correctly in the A-not-B task than those infants without this experience. These findings are supported by Acredolo, Adams & Goodwyn (1984) and Benson & Uzgiris (1985) who found that infants who had to crawl around an array were more successful at locating an object than those who were passively moved although Acredolo et al. suggest that at twelve months old visual tracking is a key component in the selection of the correct location. Kermoian & Campos (1988) replicated these findings in a variety of tasks, however they found that this improvement in searching did not extend to infants who only had experience of belly crawling as a means of locomotion. They suggest that this may be due to the increased attentional demands of this form of locomotion. These findings support the Piagetian concept that action-based knowledge is key in cognitive development. Cohen (1982) suggests that active movement predominantly facilitates the acquisition of knowledge in large-scale environments and not in situations where the entirety of a space can be viewed from a single vantage point.

It is suggested that locomotor experience, rather than improving spatial memory per se, leads only to situation specific improvements in spatial knowledge. Clearfield (2004) found that although experienced crawlers were able to successfully complete place learning and cue learning tasks, novice walkers performed poorly despite having had equal amounts of crawling experience. These results along with those of others (Adolph, 1997; Adolph, Eppler & Gibson, 1993; Berenthal, Campos & Barrett, 1984) suggest that the knowledge and skills learnt during one type of locomotor experience do not transfer to another. However, Clearfield (2004) also found that, contrary to the findings of Bremner (1978a, 1978b), eight month olds were unable to find a location by cues. It is possible that the extra cognitive demands proposed by Kermoian & Campos (1988) if placed upon the infant by the need for locomotion, especially when these skills are newly acquired, may to some degree explain Clearfield’s (2004) findings.
Studying the spatial abilities of children who are blind from birth is one way of gauging to what degree spatial abilities and knowledge are innate or subject to maturational rather than experiential influences. Many researchers suggest that visual experiences are critical for providing an external frame of reference for coding spatial information (Pick, 1974, 1981; Warren, 1984; Warren, Anooshian & Bollinger, 1973). Casey (1978) found that congenitally blind children perform more poorly than partially sighted children in constructing tactile maps of their school campus, showing poorer attention to overall organisation. Casey (1978) also reports that spatial inferences are more accurate in sighted than blind children (also Rieser, Lockman & Pick, 1980; Worcel, 1951). Blind children have also been found to be poorer at relocating in a spatial context (Rieser, Guth & Hill, 1982) and to use self referent coding more than blindfolded sighted children (Millar, 1979; O'Conner & Hermelin, 1975) suggesting that landmark strategy use is less developed. Studies of children blind from birth generally show abilities which, whilst suggesting that spatial abilities are not completely absent, are generally inferior to their sighted counterparts.

It has long been argued that the spatial abilities displayed by young children who have been blind from birth are at odds with the constructivist, empiricist view of cognitive development postulated by Piaget (1953) and his colleagues. Spelke & Newport (1998) are amongst the fiercest proponents of the innate basis of spatial coding, arguing that early spatial coding and development are independent of experience and environmental input. Landau et al. (1981, 1984) report the case of a young blind child of two-and-a-half and suggests that her ability to infer routes between points in a room on the basis of other previously taught routes indicates a Cartesian knowledge of space. Further studies of the same child suggest that by the age of three she had acquired the same knowledge of spatial prepositions and terms as her sighted counterparts and appreciated the spatial properties of distance, orientation and barriers to sight (Landau & Gleitman, 1985). However this research has as its basis a very restricted sample pool and aspects of the methodology suggest that Landau et al. may have overestimated the abilities of these children.

Morrongiello et al. (1995) analysed the paths taken by blind and sighted children in their study and concluded that, in contrast to the findings of Landau and colleagues (1981, 1984) there was substantial inaccuracy in the routes of the youngest
children and suggest that there is no evidence that Euclidean geometry is present by the age of two. They do however concede that visual experience is not necessary for the establishment of a system of spatial knowledge. They found no differences in terms of accuracy of initial turn, closest position or directness of route between blind and sighted children although there were differences in the accuracy of their final position.

There is still some dispute regarding the exact nature of children’s spatial abilities at birth. However, the prevailing opinion is that infants are more perceptually and spatially competent than proposed by the empiricist viewpoint. It appears that, whereas environmental input may influence the development of spatial abilities, spatial knowledge can develop to some extent in the absence of visual input. The next chapter examines the pattern of spatial development from infancy through childhood.
The Process of Development

Although the theoretical perspectives regarding spatial development differ with regard to the extent of abilities present at birth and the role of experience in the development of these abilities, none would suggest on the basis of empirical evidence that the young child’s abilities are identical to those of the adult. Whereas there is evidence that adults do not always display the hypothesised mature levels of performance postulated by Piaget (1956) and are often prone to errors and distortions in their judgements (Hirtle & Jonides, 1985; Hirtle & Kallman, 1988; Kuipers, 1982; McNamara & Diwadkar, 1997; McNamara, Hardy & Hirtle, 1989; Sadalla, Burroughs & Staplin, 1980), developmental changes are evident throughout the lifetime. Indeed ageing populations often show patterns of performance that mirror those of the developing child. The next section aims to look at the development of spatial abilities and discuss the processes by which this may occur.

The development of spatial knowledge

There is general agreement that spatial abilities develop over time. Newcombe & Huttenlocher (2000), reviewing the literature on spatial tasks, suggest that:

‘a consistent age-related improvement was seen in children’s ability to judge distances, compare and plan routes and construct and evaluate external representations of spatial configurations, including maps, diagrams and drawings’ (page 99)

There is a vast area of debate concerning the nature of spatial development. One debate concerns whether spatial knowledge develops as a continuous sequence or as a series of stages. Given that children’s spatial abilities do appear to be different to those of adults, the question is whether these differences are qualitative or quantitative. Both empiricist and nativist researchers are able to view development as quantitative and continuous in nature. Nativists see development as a maturation or refinement of pre-existing abilities, whereas empiricists view development as an accumulation of skills and knowledge from interaction with the environment.

Piaget’s theory, on the other hand, suggests that qualitative, discontinuous (stage-like) development occurs. Piaget & Inhelder (1956) and Hart & Moore (1973) argue that environmental understanding is more than simply a process of knowledge accumulation and follows ordered stages based on the child’s cognitive capacity.
As seen in earlier sections, recent research in the area of spatial development has demonstrated competence on Piagetian spatial tasks at a very early age when tasks are altered or simplified. Those advocating a continuous developmental sequence might suggest that whilst adults and children have similar logical competencies, levels of performance increase with age only due to increased ability to cope with such factors as task complexity and lack of contextual relevance. Piaget's stage theory has further been attacked on the basis of the extent to which 'horizontal decalage' has been found to exist in cognitive tasks (Bigelow, MacDonald & MacDonald, 1995; Kreitler, 1989). The fact that children can appear to display different stages of ability depending on the type of task they are performing (e.g. Keller & Hunter, 1973) questions the existence of domain-general qualitative changes. Kreitler (1989) however suggests that decalage represents, not differences in stages of cognitive processing but mastery and skill in the domains and cognitive processes involved. Pinard (1975) argues that children may display behaviour that appears to indicate operational thought but lack of understanding means their level of reasoning is still pre-operational. Siegler (2000) on the other hand proposes that children display differences in problem solving strategies both between and within tasks and that development is a gradual continual process of adapting strategy use. Change will be particularly gradual where a new approach does not offer a large advantage relative to the existing approach.

In the area of spatial development, Newcombe & Learmonth (1999) suggest the dichotomy between change and continuity is false. They suggest that whereas there are obvious differences in performance of children of different ages these differences may reflect not a qualitative shift in ways of coding and responding but rather a quantitative shift in reliance on different methods of spatial coding. This idea is supported by Spencer & Hund (2003) who found strong evidence for continuity in the processes underlying spatial recall. An analysis of performance on spatial memory tasks suggests that formal models of continuous development (Category Adjustment and Dynamic Field theories) can both account for the spatial memory biases that typically occur in these tasks.

Newcombe (1982) suggests that there are three ways in which a child's performance on spatial tasks may change with age; the shift from topological to Euclidean concepts; the change from reliance on landmarks and routes to configural knowledge and the ability to conserve distance and length. Sadalla, Burroughs &
Staplin, (1980) however, have shown non-commutativity in distance judgements in adults when one location is a salient landmark (reference point) and the other is not, suggesting that these changes are not always evident. Newcombe (1982) suggests that there is little evidence of young children being able to encode location in coordinate space or make spatial inferences from route knowledge to construct configural knowledge and also states that there is no evidence for conservation of distance or length in young children on spatial tasks.

Whilst Newcombe (1982) suggests that young children’s performance differs from that of adults in the majority of cases, she points out that, in certain circumstances, adults also show these same patterns of spatial coding and argues that this may be either the result of an effort-accuracy trade off or the result of novel situations or environments. Distortions, biases and inconsistencies occur in adult spatial processing and spatial memory (Hirtle & Jonides, 1985; Kuipers, 1982; McNamara & Diwadkar, 1997; McNamara, Hardy & Hirtle, 1989).

One key area of spatial development appears to be the way in which spatial location is coded. According to Newcombe & Learmonth (1999) as well as many other researchers, spatial location can be coded according to a viewer referenced system or an externally referenced system. Within these two systems there are further subdivisions. Hence a viewer-referenced system can locate objects in terms of one’s movements to the location of the object (response learning or sensorimotor coding—also known as egocentric coding) or in terms of distance from one’s current position after movement (dead reckoning). Similarly externally referenced coding can be based on the presence of coincident landmarks (cue learning) or on the basis of distance and direction from distal landmarks (place learning).

Newcombe & Learmonth (1999) suggest that although infants may typically demonstrate particular modes of encoding space at least three of these forms of spatial coding are available from or very near to birth. The most complex of these, place learning using distal landmarks, does not appear to be utilised until 21 months (Newcombe et al., 1998) and may be reliant on hippocampal maturation (Magnan et al., 1994). Parker & Walley (1988) found differential effects of hippocampal stimulation in rats using cue learning and place learning strategies in the Morris Water Maze. Newcombe & Learmonth suggest that reliance on each of these systems shifts developmentally according to which is most appropriate to the child’s experience and that the apparently qualitative shift can be explained in quantitative terms.
Research in general has tended to support the idea of a qualitative shift from initial sensorimotor coding in very young infants to allocentric (non-egocentric) coding although not necessarily over the time scale proposed by Piaget. In particular there is evidence of non-egocentric coding at early ages. Acredolo (1978) found nine-month-old children were able to make objective rather than egocentric searches for objects when they feel secure in an environment. Newcombe & Huttenlocher suggest that all types of coding are used by both adults and children. Newcombe & Learmonth (1999) suggest that response learning (based on one’s motor movement) and cue learning (based on coincident landmarks) are simple systems. They do not show developmental change (Newcombe & Huttenlocher, 2000) whereas dead-reckoning and place learning show increased fine-tuning with age. Both fine-grained and categorical coding have been observed by six months of age and Huttenlocher, Hedges & Duncan (1991) suggest that both adults and children display fine-tuning and categorical coding of place.

The suggestion that children and adults have a variety of forms of place coding available to them is borne out by empirical evidence. One form of location coding which appears common amongst young infants but by no means exclusive to them, and which gives support to Piaget’s concept of the sensori-motor stage is response learning. There is evidence that, in very young infants, coding of the location of objects relates to the pattern of muscular movements associated with reaching or acquiring that object. As cited earlier, studies have repeatedly shown evidence for the ‘A not B’ error in very young infants below the age of 8 months (Bower & Paterson, 1972; Evans & Gratch, 1972; Gratch, 1974; Gratch & Landers, 1971) and these findings are taken by the proponents of Piaget’s theory to support the idea that the young infant has no concept of space other than defining it in terms of his/her own motor actions. Newcombe & Huttenlocher (2000) point out that this method of locating an object is a highly efficient one in situations where neither the infant nor the object are capable of movement, but it ceases to be useful once either are capable of changing location.

An alternative method of location coding is that of dead reckoning. Dead reckoning is the updating of one’s position and hence the relative position of other objects based on the distance and direction of one’s own movements. Evidence seems to suggest that this process is often automatic and occurs with varying degrees of accuracy. Dead reckoning has been shown to be present in the navigational systems of animals and particularly birds. However it is subject to ‘drift’ and evidence suggests
that animals and birds frequently ‘reset’ internal navigational systems on the basis of external cues such as familiar landmarks or the rising sun (Etienne, Berlie, Georgakopoulos & Maurer, 1998; Griffin & Etienne, 1998).

Six-month-old infants are able to use simple dead reckoning as long as they have experienced producing the types of motion they need to take into account. For instance they can take into account changes in position when trained at a tilt but tested upright (Rieser, 1979) and by eight months can compensate for rotations to the left and right (Landau & Spelke, 1988; Lepecq & Lafaite, 1989; McKenzie, Day & Ihsen, 1984; Reiser & Heiman, 1982; Tyler & McKenzie, 1990). Children can also account for lateral movement along one dimension at nine months old (Landau & Spelke, 1988). Acredolo, Adams & Goodwyn (1984) suggest that at eighteen months old children are able to update their position in terms of both rotation and movement to retrieve an object from under one of two covers although at twelve months it seems to be reliant on the ability to visually track the object during movement. Bremner, Knowles and Andreasen (1994) suggest that this task is solved in terms of transformational rules rather than a true sense of updating their position and that dead-reckoning cannot be used in a precise way until after twenty-four months.

Newcombe, Huttenlocher, Drummey & Wiley (1988) suggest that children have an advanced capacity for dead reckoning at sixteen months of age. Toddlers in their study showed an ability to search for objects in the correct area of a rectangular sandbox following rotation and translation. They suggest that there is no evidence that this ability improves between sixteen and thirty-six months of age. However it may improve after this age with an increased calibration of the dead reckoning system between four years and adulthood (Rieser & Rider, 1991). Rieser & Heiman (1982) found that infants of eighteen months old and some fourteen-month-old infants could find the shortest route back to the location of an object.

A method of location coding that appears later in infancy is that of cue-dependent coding, also known as landmark use. Locations are coded according to their proximity or position relative to other objects. Landmarks (or reference points) can be points or areas and can be used either proximally as in the case of cue learning or distally as in the case of place learning. Research by Rider & Reiser (1988) suggests that when cues are available this system is used in preference to dead reckoning. They asked two year olds to point to their mothers after having been led
down a pathway either in the dark or in the light and found performance to be superior in the dark.

Cue dependent coding places a reliance on coincident objects at or very close to the location to be coded. Both adults and children make use of landmarks in their spatial representations (Acredolo, Pick & Olsen, 1975; Carr & Schissler, 1969; Siegel & Schadler, 1977) and McDonald, Spetch, Kelly & Cheng (2004) suggest that young children use landmarks proximally rather than distally. Bremner (1978) and Acredolo & Evans (1980) suggest that infants of nine months and six months old can use cues to locate an object provided they are particularly salient. However Gouteux & Spelke (2001) found that disoriented infants of less than twenty-four months fail to use even coincident landmarks and Hermer & Spelke (1996) found that configural information about landmarks is not used.

Although there is evidence to suggest that adults are generally in agreement as to what constitutes an appropriate landmark on wayfinding tasks (Carr & Schissler, 1969), Allen, Kirasic, Siegel & Herman (1979) suggest that adults and children often select different features as landmarks in a route finding task and that children are less capable of judging potential value of landmarks. They suggest that landmark use precedes the ability to assess information value. In large-scale situations children are better at locating items in differentiated rather than undifferentiated environments (Acredolo, Pick & Olsen, 1975). In addition, Herman & Siegel (1978) found that kindergarten children (5-6 year olds) were worse than grades two and five, (seven to eight year olds and ten to eleven year olds) at finding locations in a model village in large undifferentiated environment but not in smaller, differentiated environment. Liben, Moore & Golbeck (1982) report that preschoolers better at placing objects bordering on permanent landmarks than those that do not. This supports the idea that young children are especially reliant on landmarks. It has been proposed that children progress from reliance on landmarks to learning routes which connect landmarks and that landmark use is an important element of the development and construction of cognitive maps (Siegel & White, 1975). Curtis, Siegel & Furlong (1981) found configurational knowledge improves developmentally but landmark and route knowledge do not.

A more sophisticated form of location coding is the use of distal landmarks to code location. This develops in conjunction with configurational knowledge of locations. Evidence seems to suggest that very young children are not able to use
distal landmarks to guide their search behaviours. DeLoache and Brown (1983) found that children of twenty-six months could not find a toy hidden in one of four identical containers when they needed to code information about distance and direction from landmarks such as furniture to complete the task. Mangan, Franklin, Tignor, Bolling & Nadel (1994) found that children below the age of twenty-four months were unable to use distal cues in a circular search environment. Newcombe et al. (1998) suggest that there is a change in ability to use distal cues between sixteen and thirty-six months old with no evidence of the use of distal landmarks before the age of approximately twenty-two months. Similarly, research has shown that rats below the age of twenty-one days are unable to use distal landmarks in the Morris Water Maze (Rudy, Stadler-Morris & Albert, 1987) suggesting a maturational aspect to this ability.

Results concerning differences between older and younger children’s ability to use distal landmarks might suggest a developmental shift from topological to Euclidean coding (Acredolo, Pick & Olsen, 1975; Herman & Siegel, 1978). However Huttenlocher & Newcombe (1984) suggest that although younger children (five year olds) may show a greater number of errors in situations where only distal landmarks are available, they still have a reasonably accurate idea of the location of the object and show high levels of configurational and relative accuracy even when only distal landmarks are available. Pentland, Anderson, Dye & Wood (2003) measured children’s performance on the Nine Box Maze test and concluded that:

‘the basic foundations of distal place learning are present in the young child’ (five to six year olds) ‘and subsequent development represents quantitative rather than qualitative changes.’ (Page 152)

Children’s knowledge of large-scale environments becomes more accurate over middle and late childhood and one suggestion is that this reflects their increasing ability for hierarchical coding and fine-grained tuning.

Spatial memory, spatial categorisation and hierarchical coding

One important area of development is in the way that children organise and structure large-scale and small-scale space and how locations are coded within that space. All spatial environments can be said to have a hierarchical structure, smaller areas are related to each other and embedded within larger areas. Areas of space may be divided into categories and this categorisation can take place according to
functional or locative factors. One primary aim of the coding of locations in space is to enable us to locate the same point from memory.

The Piagetian view of the coding and retrieval of spatial location in memory suggests internal representations of object locations appear only when the infant has achieved object permanence at around the age eight months. During the preschool years the representation of objects is topological (cue dependent) and projective and Euclidean systems of location are not used until later childhood. However, there is evidence that both children and adults use a hierarchical form of spatial representation with a reliance on categorical and fine-grained (metric distance and direction) coding (Hund & Plumert, 2002; Huttenlocher, Newcombe & Sandberg, 1994). Huttenlocher, Hedges & Duncan (1991) propose that categorical and fine-grained information are combined to give a best estimate of location (Category Adjustment Model). Newcombe & Huttenlocher (2000) suggest that children as young as six months have been shown to display both categorical and fine-grained coding of space and that throughout childhood children progress and subdivide given areas into smaller areas. In addition there is a developmental change in children’s ability to combine hierarchical data along two dimensions.

Hierarchical coding has been observed as early as sixteen months. Huttenlocher et al. (1994) found prototypical effects in search tasks using a rectangular sandbox. Children between two and ten years old were shown an object being hidden and had to retrieve the object after a short delay. The results showed that the children were able, even at an early age, to code location metrically and that their responses showed systematic biases towards the centre of the sandbox in the case of younger children, and the centre of the half of the sandbox the object was hidden in the case of older children above the age of six. These geometric biases have also been found in adults and children in a variety of other tasks (Engebretson & Huttenlocher, 1996; Huttenlocher, Hedges & Duncan, 1991; Laeng, Peters & McCabe, 1998; Newcombe & Liben, 1982, Newcombe, Huttenlocher, Sandberg, Lie & Johnson, 1999; Plumert & Hund, 2001; Schutte & Spencer, (2002); Spencer, Smith & Thelen, 2001).

In addition to geometric biases in spatial recall there is also evidence that delays in recall lead to spatial drift in recall (Schutte & Spencer, 2002, Spencer & Hund, 2002), such that when a delay is introduced, subjects typically display more prototypical responses showing displacement towards central locations within a sector.
of space. This displacement suggests a greater reliance on categorical information in situations of uncertainty. In addition recall is often influenced by previous task locations often showing a bias towards a prototypical, central location of a set of stimulus locations (Spencer & Hund, 2002) suggesting that induced category effects arise (Huttenlocher et al., 2000).

**Children’s understanding of large-scale environments**

Children’s environmental competence can be measured by the degree to which they are able to locate objects in small-scale and large-scale space and to navigate their way from one location in space to another. The child’s understanding of the environment around them expands from the immediate environment surrounding them to the world outside. As the infant moves through space independently so it attends to (Freedman, 1992) and develops a greater sense of large-scale space (Acredolo, 1978; Bremner & Bryant, 1985). Through exploration and play the child becomes more acquainted with the large-scale environment (Bruner & Connolly, 1974; Hughes, 1978; Schoggen & Schoggen, 1985) and gains mastery of and adaptation to the environment (Arnaud, 1974). With increasing age children cover greater areas in their outdoor play and exploration (Hart, 1979; Michelson & Roberts, 1979), increasing their knowledge of surrounding areas. With increased knowledge of an area children’s sketch maps of them become more detailed and accurate and encompass wider areas (Wapner, Kaplan & Ciottone, 1981). Knowledge of individual areas must somehow be pieced together to allow a comprehension of large-scale spaces. The process of achieving a grasp of large-scale environments is complex and the study of this process equally so.

Although environmental knowledge is constrained by age in the sense that mobility and degree of exploration are limited by the child’s age, other factors also limit the degree of knowledge of the environment displayed by children. It has been noted that girls sometimes display poorer spatial skills than boys. One possible explanation of this is that girls have different opportunities to encounter and explore the environment (Matthews, 1986, 1987) due either to greater restrictions imposed upon them by parents or due to more passive styles of interaction with the environment (Coates & Bussard, 1974; Matthews, 1987; Payne & Jones, 1977). Social characteristics also have some bearing on children’s environmental knowledge. Bronfenbrenner (1967) suggests that the environmental ranges of middle-class
children were much more restricted than those of working class children. He suggests that working class children explore and experience a greater area around and outside the home than middle-class children. However, more recent research suggests that children’s environmental opportunities increase with socioeconomic class (Orleans & Van Vliet, 1983; Ward, 1977). It may be that whereas children in wealthier families have more opportunity to travel outside the immediate home environment, those from the working class families in Bronfenbrenner’s study had greater opportunity for independent environmental exploration. Joshi, MacLean & Carter (1999) suggest that children who have greater freedom to travel without an adult on non-school journeys show greater use of landmarks than those without.

**Wayfinding**

Evidence concerning configurational knowledge about the location of objects has often taken the form of studies of object location, landmark and wayfinding studies in large-scale environments. It has been argued that route knowledge is frequently based on landmark use and in young children route knowledge is often not reversible (Piaget, Inhelder & Szeminska, 1960). Studying children’s wayfinding abilities provides an insight into their internal spatial representations. Wayfinding refers to the ability to navigate effectively through the environment (Blades, 1997) and is a high level spatial ability demanding declarative and procedural knowledge as well as landmark, configurational and route knowledge. Downs (1976) suggests that route learning is a basic component of cognitive mapping.

The term 'cognitive map' was coined by Tolman (1948) to explain the behaviour of rats in maze conditions and is used as a metaphor to summarise a person's environmental knowledge. Distinctions have been made concerning internal representation of space between 'network maps' which are essentially topological in nature and 'vector maps' which contain information about distances and bearings (Byrne, 1979, 1982) and relate to the real layout of the world. Chase (1983) suggests that expert wayfinders, such as taxi drivers, use a 'skeleton' of important pathways and landmarks to guide them.

Hazen, Lockman and Pick (1978) suggest children are competent wayfinders. Wayfinding can take a variety of forms including the ability to use a map or model to negotiate a maze in larger space, retracing novel routes, reversing a previously learned or experienced route and the ability to choose the shortest route to return to a point on
the basis of previous movement (Blades & Spencer, 1987; Bremner & Andreasen, 1998; Cornell, Heth & Rowats, 1992; Darvizeh & Spencer, 1984; Rieser & Heiman, 1982). The most direct method to investigate children’s wayfinding is to ask children to walk particular routes either in small-scale (Cohen & Cohen, 1982; Herman, 1980; Herman & Roth, 1984; Presson, 1987; Siegel, Herman, Allen & Kirasic, 1979) or larger scale (Hazen, Lockman & Pick, 1978) laboratory environments, or real or simulated routes (Cornell & Hay, 1984; Cornell, Heth & Rowat, 1992; Darvizeh & Spencer, 1984; Gale, Golledge, Pellegrino & Doherty, 1990).

Siegel & White (1975) propose that children and adults learning new environments develop configurational knowledge by initially learning about individual landmarks, which are then linked to actions. These landmarks and action become linked to form all or part of a route and when several of these become linked together by the presence of shared elements, they form an accurate representation of a small area or location (a ‘mini-map’). When several mini-maps become integrated into a larger area on the basis of topological relations, then this knowledge (survey knowledge) forms an accurate representation of a particular location.

Whilst both Siegel & White (1975) and Piaget et al. (1960) stress the importance of route learning on survey knowledge, whereas Piaget et al. emphasise the motor basis of route learning, Siegel & White suggest that prior to route learning the acquisition of landmark knowledge is important. This is supported by research by Anooshian & Nelson (1987) that suggests that the first mental models are indeed representations of a sequence of landmarks. The selection of environmental elements may be goal-specific and wayfinding in children is aided by instructions to use environmental landmarks. Cornell, Heth & Broda (1989) found six and twelve year olds showed less deviation from a route if landmarks on a path were pointed out than when they were not and that twelve year olds wandered off a path less if distal landmarks were pointed out than if they were not. However they did not find evidence to support the idea that informing the child that they will have to find their way back improves performance.

The spatial knowledge needed for successful wayfinding includes the elements of distance and direction. Estimates of direction in young children have been studied as a means of inferring knowledge of the environment that is not topological in nature. Usually the study of directional knowledge takes the form of asking the child to point to a variety of locations that are not visible. Conning & Byrne (1984) studied
children’s abilities to point to out of sight locations and found that some children between the ages of three-years-five-months and four-years-seven-months showed consistent vector map/Euclidean knowledge despite Piaget’s contention that pre-school children are limited to topological representations of space. Of note were the findings that this Euclidean knowledge developed earliest in very familiar settings such as the home and also that children often appeared to abandon network or path based responses before an accurate vector map knowledge was in place. This was supported by Lehnung, Haaland, Pohl and Leplow (2001) who found that pre-school children are capable of making exact bearing estimations and have good spatial knowledge when asked to point towards a landmark by rotating their body and using an outstretched hand. Similar results have been found by Neidhart (1999), cited in Lehnung et al. (2001) who found that five year olds were especially able to make accurate bearing estimates when no ‘barriers’ in the form of very high buildings were in the way. Other studies also suggest that accuracy increases with age (Curtis et al., 1981; Cousins et al., 1983). However, it is possible that rather than reflecting Euclidean knowledge of spatial relationships, the children were merely updating their knowledge of the direction of the object from themselves during movement.

Understanding maps and models

Children’s understanding of maps and models gives both an insight into the nature of spatial competence and their ability to understand representational information. Maps and models are essentially graphical representations of space. They typically differ in terms of dimensionality, scale and iconicity/arbitrariness of symbols (Newcombe & Huttenlocher, 2000). Two types of information are contained within maps, representational or element-to-element correspondence and correspondence of geometric or spatial relationships (Bluestein & Acredolo, 1979, Downs, 1985; Liben & Yekel, 1996; Presson, 1982). Representational correspondence is the basic component of map and model use, the understanding that each element on the map has a one-to-one correspondence to items in the physical world allows for success in some cases on the basis of cue learning. Geometric correspondence is more complex relying on both notions of scale and alignment.

Nativists such as Blaut (1997) suggest that children have innate mapping skills and that mature representational thinking is present in humans from birth. According to Blaut, the early mapping (protomapping) skills of children are typified by: a) use of
signs to represent features in the landscape, b) ability to show environments from an overhead perspective and c) ability to scale down to map or model size.

Evidence seems to show that there may be some early readiness for symbolic representation. From the age of two years old children show the ability to understand the symbolic notion of pictures and photographs as representations of space (DeLoache, 1989; DeLoache & Burns, 1993, 1994; Dow & Pick, 1992) although DeLoache (1995) suggests that young children have difficulty with the concept of a model as a representation of something else and see the model as an object in its own right. From four years old children can use aerial photographs to identify features (Blaut, McCreary & Blaut, 1970; Blaut & Stea, 1971, 1974) and locate hidden objects (Plester, Richards, Blades & Spencer, 2002) although their understanding may be incomplete (Liben & Downs, 1989). Young children tend to display an inconsistency in scaling when interpreting aerial photographs, maps and models, (Liben & Yekel, 1996; Uttal, 1996) although Huttenlocher, Newcombe & Vasilyeva (1999) suggest that 4 year olds and a fair proportion of three year olds show the ability to encode proportional distances in a sandbox task. Young children have also been shown to be able to solve navigational problems using aerial photographs and basic maps (Reiser et al. 1982; Scholnick, Fein & Campbell, 1990; Uttal & Wellman, 1989) but have difficulty in interpreting unaligned maps (Blades, 1991; Blades & Spencer, 1987, 1990; Bluestein & Acredolo, 1979; Liben & Downs, 1989; Presson, 1982).

Downs & Liben (1997) argue that young children cannot deal efficiently with maps and cannot understand both representational and spatial (e.g. scale, orientation, angle and geometric projection) nature of maps. Their results suggest that although the representational aspects of aerial photographs and maps may be readily grasped, confusions can result due to scaling for example, Liben & Downs (1991) report children mistaking boats on a lake for fish. Finally, evidence suggests that efficient map use is not a universal feature of adult spatial understanding; many adults are reluctant to rely on maps in order to navigate, preferring to rely on road signs or directions (Blades & Spencer, 1986).

The Use of Spatial locative terms

The use of spatial locative terms in young children is thought to reflect the child’s underlying perceptions of space (Clark, 1973) and the order of acquisition of spatial locatives is a reflection of the conceptual difficulty of spatial relationships.
(Clark, 1973; Corrigan, Halpern, Aviezer & Goldblatt, 1981). Landau & Jackendoff, (1993) suggest that the categorical nature of spatial language reflects the categorical nature of spatial coding and a lack of metric precision. However studies suggest that both adults and children are capable of fine-grained accuracy in spatial memory and motor tasks (Huttenlocher, Hedges & Duncan, 1991; Huttenlocher, Newcombe & Sandberg, 1994). Alternatively researchers such as Levinson (1996) and Pederson (1995) suggest that the nature of spatial terms within a language affect the ways in which people encode space and that children acquire different spatial concepts according to the prevalence of the spatial terms in the language they hear (Choi & Bowerman, 1991; Gopnik & Meltzoff, 1986).

Around the age of two children can understand basic spatial locative terms (Brenner & Idowu, 1987; Cox & Richardson, 1985; Plumert & Hawkins, 2001). Words expressing concepts such as in, on, under and beside are acquired before such words as between, in front of or behind (Johnston & Slobin, 1979). These findings would seem to suggest that topological spatial relationships are acquired before projective relationships, lending support to Piaget & Inhelder’s (1956) theory concerning the child’s conception of space. Cox & Richardson (1985) found that three year olds showed higher levels of accuracy on spatial terms used for vertical (up/down) dimensions than for back/front and left/right dimensions and that young children between three and six years old showed better performance on front/back spatial terms than left/right terms. If Clark’s (1973) hypothesis that spatial locatives reflect underlying perceptions of space is correct, this difference in accuracy might also be expected to manifest itself behaviourally in tasks involving left/right and front/back dimensions.

Whilst young children seem to have a reasonable understanding of most basic spatial locatives they hear, and interpret them similarly to adults, there is some evidence that some more complex spatial relationships take time to master. Sowden & Blades (1996) found that young children of three and four years old appear to make no distinction between the term ‘next to’ and ‘near to’ whereas six year olds show similar patterns of differentiation to adults. Terms may be ambiguous when they depend on correct interpretation of the desired frame of reference. For example ‘in front of the doll’s house’ might be interpreted as being ‘outside the front door’ or alternatively ‘between the dolls house and yourself’. Research suggests that young children spend little time establishing common spatial referents in comparison to
adults (Taylor & Klein, 1994, cited in Newcombe & Huttenlocher, 2000). Young children of three and four years old often fail to use landmarks or frames of reference to describe the location of objects to others even though they use these in their own spatial codings (Craton et al., 1990) and furthermore are more likely to provide disambiguated information in nested relationships when spatial relationships involve containment as opposed to proximity.

Evidence suggests that substantial development takes place in young children’s ability to both code location and navigate small-scale and large-scale environments and to verbally describe locations to others. Much debate concerns whether this development is the result of qualitative or quantitative change.
Mechanisms of Development

Although much is known about children’s use of different spatial codes at different ages, relatively little attention has been paid to the processes by which this change occurs. There is some general agreement that Piaget underestimated the extent of the newborn infant’s cognitive mechanisms and over emphasises the role of domain general cognitive development. More recent interactionist accounts (Edelman, 1992; Elman, Bates, Johnson, Karmiloff-Smith, Parisi & Plunkett, 1996; Gopnik & Meltzoff, 1997; Karmiloff-Smith, 1992; Siegler, 1996) suggest that biologically specified abilities interact with environmental input to allow new expressions of these abilities. It is argued by Newcombe & Huttenlocher (2000) that a commonality of development will occur because in many cases environmental input is: ‘universally available and without any real variability’. (Page 209). The relevance of some of these ideas to the area of spatial development is discussed below.

Representational Redescription

Karmiloff-Smith (1992) argues that general sensorimotor activity cannot explain all developmental processes, especially not in the area of language development. Whereas she agrees with the Piagetian principle that infants and young children are active constructors of their own cognition, she suggests, unlike Piaget that this involves both domain specific constraints and domain general processes.

Although Karmiloff-Smith pays little attention to the child’s conceptual understanding of space, focussing instead on the child’s understanding of mathematical and physical properties, the questions she raises regarding the role of genetic and experiential factors are important. Karmiloff-Smith’s Representational Redescription Model attempts to account for the ways in which children’s representations change. Karmiloff-Smith (1992) suggests that cognitive processes are molar (i.e. not domain specific) at birth and differentiate across time, becoming more specialised as children’s representations become more manipulable and flexible which in turn allows conscious access to knowledge and also theory building. This redescription transforms implicit information into explicit knowledge that is available for use by the child. Karmiloff-Smith suggests that the process of representational redescription is domain general, i.e. it occurs in all domains but it does not occur across all domains simultaneously. In some domains or microdomains the process will occur earlier than others and representational redescription can continue into
adulthood in areas of new learning. According to Karmiloff-Smith learning and
development consist of two processes, proceduralisation, which is important for the
correct performance of a task, and explicitation, which involves conscious and verbal
access to knowledge. Evidence however seems to suggest that this explicitation is
independent of the child’s level of verbal ability. Pine & Messer (1999) found no
relation between verbal ability and ability to explain ideas about balancing.

One manifestation of representational redescription is that it predicts U-shaped
patterns of ability over the course of development with children in the early stages of
development often displaying greater success in tasks than children in later stages.
This idea is supported by observations that children may experience success in one
situation but not in another, seemingly equivalent, situation either because they have
formed no explicit knowledge regarding the task but are relying on implicit
knowledge or because they are operating on erroneous explicit rules. For example
Clearfield (2004) found that place-learning skills evident in experienced crawlers
were not apparent in novice walkers despite their having had equivalent experience of
crawling, suggesting that the knowledge being used regarding location is implicit.
According to Karmiloff-Smith representational redescription proceeds, not through
experiencing failure which produces disequilibrium, as Piaget would propose, but
through experience of success.

**Strategy choice and Strategy change**

Although theories of strategy use are usually discussed in the context of
learning and problem solving, they have some bearing on spatial tasks. In particular
theories of strategy choice and strategy change relate to Newcombe & Huttenlocher’s
views regarding the development of spatial location. As will be discussed in
subsequent sections, Newcombe & Huttenlocher (2000) suggest that children and
adults have a variety of spatial codes available to them for locating points in space.
Furthermore they suggest that adults and children choose which of these systems to
use on the basis of their effectiveness. These ideas are not dissimilar from models of
learning based on strategy choice and strategy change such as Siegler’s (1996)
‘overlapping waves’ theory which suggests that, in the realm of problem solving,
children use a variety of strategies which coexist over prolonged periods of time and
that the reliance on these strategies is changed through experience of both success and
failure (Karmiloff-Smith, 1992; Siegler & Jenkins, 1989), an idea similar to the
weighting proposed by Huttenlocher et al. (1994). Siegler (1996) proposes that these multiple strategies will result in variability between responses of individuals and research on conservation supports his idea that children use a variety of strategies at the same point in time (Siegler, 1995). According to Siegler (2000) early approaches to solving a problem may perpetuate when they are particularly effective (i.e., they are a heuristic) or where alternative strategies do not offer a large advantage because of failure to execute them efficiently (Bjorklund, Miller, Coyle & Slawinski, 1997; Miller, Seier, Barron & Probert, 1994).

Category Adjustment theory

According to Newcombe & Huttenlocher (2000) children and adults possess the ability to use four types of spatial coding, response-based, cue-based, dead-reckoning and place learning. These sources of information are frequently combined when estimating a location and the weight given to each of these methods of spatial coding is dependent upon an ‘accuracy versus cognitive effort’ trade-off. Therefore in situations where accuracy is achievable using egocentric methods then this method is used. The child develops a sense of appropriate methods of spatial coding on the basis of successful interactions with the environment.

The place-learning system has been the focus of much research. Huttenlocher, Hedges & Duncan (1991) suggest space is coded hierarchically and put forward a Category Adjustment theory to describe how, in situations of uncertainty, information is combined from different levels of a hierarchy to achieve a best estimate of location. Whereas neither representational redescription nor strategy choice theory makes explicit predictions regarding the nature of spatial development, category adjustment theory (Huttenlocher, Hedges & Duncan, 1991) makes many of its assumptions on the basis of empirical studies of children’s and adults’ performance on spatial tasks and in particular, the retrieval of spatial information from memory. Studies of adults’ and children’s memory for location have revealed the existence of prototype effects, consistent biases towards the centre of an area of space (Engebretson & Huttenlocher, 1996; Huttenlocher, Newcombe and Sandberg, 1994; Laeng, Peters & McCabe, 1998; Sandberg, Huttenlocher & Newcombe, 1996). In addition prototype effects have also been noted in studies of time (Huttenlocher, Hedges & Prohaska, 1988) and stimulus characteristics (Huttenlocher & Hedges, 1994). Spatial prototype effects have been noted in children between the ages of two and ten years old (Huttenlocher et al., 1994).
and, with increasing age, children show evidence of subdividing space into smaller sections.

According to the Category Adjustment theory, the retrieval of locations within memory is organized hierarchically and is a two-step process involving the use of both fine-grained metric information and categorical information. The suggestion is that when trying to remember the location of an object, people initially make estimates on their memory of information such as distance and direction from an edge and adjust these estimates on the basis of categorical information. This adjustment takes place in situations of uncertainty, such as those following delays, and is based on increasing the likelihood of a correct location through the use of this information. Categorical information is based on a spatial prototype located at the centre of a region and so leads to biases. This metric then categorical order of retrieval might seem counter-intuitive. We are used to thinking of a hierarchical system as pinpointing more and more exactly within a region of space.

Evidence suggests that categorisation (Engebretson & Huttenlocher, 1996; Huttenlocher et al., 1994) and fine-grained information (Huttenlocher et al., 1991; Sandberg et al., 1996) are present in the spatial representations of adults and children. Indeed this suggestion of both a categorical and a metric system for encoding space is supported by evidence for hemispheric localisation of categorical and coordinate spatial relations (Kosslyn et al., 1989; Laeng & Peters, 1995; Rybash & Hoyer, 1992).

There is evidence that young children's categorisations differ from those of older children and adults in that they may subdivide space into fewer categories and be more reliant on visible category boundaries (Huttenlocher et al., 1994). The age at which children subdivide space further seems to depend on the size of the space to be subdivided (Huttenlocher et al., 1994) with smaller spaces apparently more prone to subdivision than larger ones. Although visible boundaries have been shown to be important in the categorisation of space (Quinn, 1994; Quinn, Cummins, Kase, Martin & Weissman, 1996), categories may be formed not simply on the basis of location. Children and adults have been found to group locations together that they have experienced close together in time (Hund, Plumert & Benney, 2002) and biases suggest that learning nearby locations close in time increases the weighting given to categorical information during recall. Similarly Hund & Plumert (2003) suggest that the conceptual categorisation of objects can influence the degree of spatial bias shown in estimates of distance between objects, again suggesting that the weighting given to
categorical information increases with object similarity. Sandberg, Huttenlocher & Newcombe (1996), suggest that children do not begin to use categorical prototypes on both dimensions in two-dimensional tasks until after the age of seven.

It has been proposed that Category Adjustment theory can explain biases and asymmetries occurring in a variety of spatial tasks. Category Adjustment theory successfully explains the presence of biases in estimating differences between two points and the lack of commutativity in distance judgements (McNamara & Diwadkar, 1997; Sadalla, Burroughs & Staplin, 1980). Newcombe, Huttenlocher, Sandberg, Lie & Johnson (1999) report that distance estimates between a fixed landmark (prototype) and another point (non-prototype) were often smaller than when the non-prototype was fixed. This suggests that the non-prototypical location is remembered, as a result of category adjustment, to be closer to the prototype than it is. According to Huttenlocher and her colleagues the bias towards the prototypical value of a category can also explain ‘barrier effects’ where the distances between two points separated by some sort of barrier or boundary is overestimated but the same distance between two points within an area tends to be underestimated (Acredolo & Boulter, 1984; Allen, 1981; Cohen, Baldwin & Sherman, 1978; Cohen & Weatherford, 1981; Hirtle & Jonides, 1985; Kosslyn et al., 1974; Laeng et al., 1998; Maki, 1982; McNamara, 1986; Newcombe & Liben, 1982). These areas may be formally sectioned off or partitioned on the basis of functionality.

Barrier effects do not seem to be purely the result of factors such as the functional distance between points (i.e. time or effort taken to get between one point and another) (Newcombe & Liben, 1982). Huttenlocher et al. (1991) suggest that these misestimations are due to the bias towards a region’s centre in remembering locations. However, Plumert & Hund (2001) found that differences in errors of estimation of distance between points within and between regions only occurred in older children and adults and that younger children, rather than showing displacement towards the centre of a region, showed displacement towards the corners. A second study suggests that where the salience of the boundaries between the locations is increased this displacement does not occur. It may be that the biases that occur in young children may be as a result of less reliance on categorisation of space as a cue to location and a greater reliance on the use of geographical features as reference points as noted in previous studies using the retrieval of hidden objects. Previous studies by Huttenlocher & colleagues have tended to use circular environments.

38
(Huttenlocher et al., 1991, Sandberg et al., 1996) and geometric information may not have been available. In addition, Newcombe and colleagues suggest that children do not combine categorical information on two dimensions until above the age of seven. It is possible that the pattern of errors in Plumert & Hund’s (2001) study could reflect this incomplete categorisation but only a study of individual errors would clarify whether there is a bias towards the centre on one dimension but not another as average values would not reveal this.

Whilst prototypes can be based purely on the centre of a categorical region, further research suggests that prototypes can just as easily be based on previous experiences of locations (Hund & Spencer, 2003) and this may be more prevalent in younger children. Munakata, McClelland, Johnson & Siegler (1997) suggest that biases towards hiding locations that have been experienced frequently in the past disappear as children become more reliant on current rather than latent memories and this is supported by Hund & Spencer (2003) who found reduced experience dependent effects between six and eleven year olds and in comparison to three year olds in a study by Schutte & Spencer (2002). There is evidence that a prototype may be formed as an ‘average’ value of all those experienced within a category (Huttenlocher, Hedges & Vevea, 2000). In terms of location, an area could be said to be categorised as only that region in which the to-be-remembered locations were located with the most extreme points in any direction forming the boundaries.

Category Adjustment theory suggests that as the uncertainty of fine-grained information increase, so the weighting of categorical information increases leading to biases towards spatial prototypes. Evidence for this exists in the presence of increased bias towards prototypes in adults after delays or distractor tasks on spatial memory tasks (Engebretson & Huttenlocher, 1996; Hund & Plumert, 2002).

Theoretical ideas concerning the development of spatial abilities differ with regard to whether developmental change constitutes a quantitative shift in competing strategies, a continuous change in underlying cognitive mechanisms or a qualitative, stage-like change in children’s cognitive abilities. Children’s performance on perspective-taking tasks and the use of coordinate references are frequently taken as evidence for qualitative stages in children’s development and are discussed in the following section.
Perspective Taking and the Use of Coordinate References

Piagetian theory states that developmentally children below the age of eight are only capable of viewing the world from an egocentric perspective and additionally have an undeveloped system of spatial coding in comparison to adults. Spatial organisation in children, according to Piaget & Inhelder (1956), progresses through three stages. The child initially codes space and location in an egocentric manner with the self being the point of reference. This means they are unable to decentre from their own views on space and location. However from this egocentric viewpoint the child’s ability to code location in space proceeds through three stages, the topological, projective and Euclidean until a mature system of spatial organisation is reached. However, research into perspective-taking and use of coordinate references disputes Piaget’s stance, suggesting that these abilities are present earlier than proposed.

Perspective taking

According to Piagetian theory the key component of spatial perspective taking is the development of projective coding. This means that the relationship between objects from another perspective can be identified. Mature spatial ability is considered to be the ability to organize space through the use of a coordinate reference system, which allows points in space to be defined independently of objects and to be manipulated mentally through more than one dimension.

However, research has cast doubt on Piaget’s contention that young children’s spatial coding is fundamentally different to that of adults. Whereas Piaget stresses the use of a topological system in young children there is evidence to suggest that young children have knowledge of metric distance and configuration in a variety of tasks (Bartsch & Wellman, 1988, Miller & Baillargeon, 1990). Young children seem able to metrically consider self-movement and locate objects after movement (Newcombe, Huttenlocher, Drum & Wiley, 1998) and to encode the location of objects along the length of a sandbox (Huttenlocher, Newcombe & Sandberg, 1994).

Piaget also distinguished between perceptual thought, based on direct perception of the immediate environment, and conceptual thought which enables the consideration of spatial relationships, which cannot be directly perceived. Piaget believed perceptual understanding develops in advance of conceptual understanding. This conceptual understanding is said to be the key to such tasks as Piaget’s three
mountains task (Piaget & Inhelder, 1967). In this task children are shown a model of
three mountains, each with a particular identifying feature. The children are seated on
one side and a doll is seated on another. The children are then asked to perform
several tasks: a) select which of several different pictures represents the doll’s view
from the different position around the model; b) select a picture and then position the
doll so that their view is the same as that in the picture; c) arrange three replica model
mountains to represent the dolls view. Children below the age of seven frequently
choose pictures that represent their own view of the array, (‘egocentric errors’) or
pictures that show only a partial understanding of another perspective (Piaget &
Inhelder, 1967).

Piaget argues that young children lack the ability to mentally manipulate more
than one dimension simultaneously due to their lack of a Euclidian coordinate system
and the inability to coordinate both the Near-Far and the left-right dimension
simultaneously. Although younger children (according to Piaget, those in substage
IIA) are able to transpose the Near-Far dimension they fail to compensate for
left/right reversal. Early attempts at compensation on this dimension occurring in
substage IIIA or thereabouts still show difficulty in manipulating both dimensions
simultaneously and only in substage IIIB are children able to successfully coordinate
both dimensions (Coie, Costanzo & Farnhill, 1973; Fishbein, Lewis & Keiffer, 1972;
Flavell, 1974; Laurendeau & Pinard, 1970; Minnigerode & Carey, 1974).

In addition to the inability to mentally manipulate objects in space, Piaget
argues that the young child is unable to appreciate that people in other locations than
their own have different views and so are unable to take on another’s perspective
(egocentrism). This egocentrism is present below the age of about eight years old.
According to Piaget this egocentrism extends to communicative, cognitive and
affective behaviours although Ford (1979) suggests there is little correlation between
performance on tasks designed to measure these aspects. Studies of Object Mental
Rotation (array-rotation) in comparison to Subject Mental Rotation (viewer-rotation)
in both children and adult populations (Huttenlocher & Presson, 1973; Inagaki,
Meguro, Shimada, Ishizaki, Okuzumi & Yamadori, 2002) suggest that Object Mental
Rotation ability is acquired earlier than Subject Mental Rotation and that age related
differences are more marked in Subject Mental Rotation tasks. Elderly people show a
greater proneness to egocentric errors than younger adults (Inagaki et al., 2002) and
children presented with array-rotation tasks show no evidence of egocentric errors
(Huttenlocher & Presson, 1973). This evidence suggests that perhaps egocentrism and immature spatial coding may be separate issues and that rather than spatial development progressing as a transition from a concrete and subjective (egocentric) representation to an objective abstract (Euclidean) visuo-spatial framework these two processes may be distinct yet interrelated. Problems with viewer-rotation tasks would not appear to be due to an inability to perform rotational transformations.

Although Piaget & Inhelder (1956) found that young children made a large proportion of egocentric errors on their ‘three mountains task’, a growing number of studies indicate that children have some awareness that other people’s perspectives are not the same as their own. Studies suggest that under some circumstances young children can display nonegocentric perspective taking (Flavell, Everett, Croft & Flavell, 1981; Flavell, Omanson & Latham, 1978; Lempers, Flavell & Flavell, 1977; Liben, 1978; Massangkay et al., 1974; Yaniv & Shatz, 1990). Lempers et al. (1977) found that children as young as two were aware that they had to display a drawing so that they could not see it in order for others to see it. Hughes & Donaldson (1979) found that the majority of three and four year old children were able to hide a boy doll from one or more policemen dolls and that very few made errors that could be classified as egocentric.

However it is possible for this task to be solved without any recourse to Euclidean spatial knowledge. Hughes and Donaldson suggest their task gets different results because it makes ‘human sense’ to the child. It could be however that the effort of constructing a task that makes human sense to the child has so altered the task as to make it completely incomparable. Piaget & Inhelder’s task involves more than merely the obstruction of a line-of-sight but also knowledge of left/right and front/back reversal. However research by Wallace, Allan & Tribol (2001) suggests that young children’s errors on perspective taking tasks most commonly consist of choosing a picture with left-right reversal and that even the youngest children (four to six year olds) made relatively few egocentric errors.

Bridges & Rowles (1985) suggest that children between four and seven do not automatically assume that because there is a wall between the hider and seeker the hider is necessarily hidden but also that children of this age group are often willing to ‘hide’ a doll from a monster where parts of it may be visible. One important finding is that there do seem to be important developmental differences in response. Knowledge of the limits of concealment seems to develop from a low level at age three to one of
greater proficiency at age six. Four and five year olds were more aware of the direction of sight of the monster and often overly restrictive, attributing them with ‘tunnel vision’. Whether this is a conception limited to monsters alone is not known. More six year olds than four or five year olds made adult-like responses in one task, younger children all agreed that the boy could be seen when his face was exposed but were more inconsistent if only other parts of the body could be seen. This was confounded with position of the hole in the wall and also the monster’s line of vision.

Hiding games for young children seem to tap into their knowledge of how to play hide-and-seek properly. For many three year olds hiding an object seems to involve placing it behind an obstruction. This process may then have been operating in Hughes and Donaldson’s study. It may be also that three year olds’ knowledge of playing hide-and-seek is determined by the expectations of those playing with them. Adults often act as if they are completely concealed when in fact they are only partially concealed and early hiding games such as peep-bo involve simply covering the eyes. Expectations are often increased as the child progresses. As Bridges & Rowles (1985) state:

‘if we choose to employ a familiar game as the setting for testing, then we need to be sure that the children recognize the link between the procedural characteristics of the game and the more abstract logical-mathematical principles in the same way adults do.’ (Page 265)

Newcombe (1989) suggests that success in perspective taking tasks is influenced by the attributes of the child, such as the desire for intellectual realism, and the attributes of the task, including the nature of the display and the nature of the response.

Children’s failure to perform well on tasks such as Piaget’s three-mountain task, whilst performing in a superior fashion on other tasks may be related to what Piaget identifies as intellectual realism, whereby the child attempts to show what they know to be true rather than what they see. In the three-mountains task the correct viewpoint may include the occlusion of one mountain by another. Liben & Bellnap (1981) found that three to five year old children had difficulty in selecting a picture of their own viewpoint when it featured a large block which occluded other blocks that the child knew to be there. However Pillow & Flavell (1986) suggest this may be confined to tasks where the child is asked to select a picture. Similarly children frequently omit occlusion from their drawings (Freeman, 1980; Light & Humphreys,
Light & Nix (1983) found evidence to suggest that, in tasks requiring the selection of another’s view, children frequently select a picture representing a ‘good’ view of the array, i.e. one in which all the objects present are visible in preference to their own view and that own view preference is secondary to this. Light & Nix propose that some of the supposed egocentric errors in earlier studies may have been as a result of the child’s view being a ‘good’ one and the other’s not.

With regard to the nature of the task it appears that several factors can make a substantial difference to the level of performance. One important variable appears to be the nature of the other observer. Cox (1975,1977a) and Fehr (1979) have both found differences in levels of accuracy with people as the ‘other’ compared to dolls or blindfolded people (Fehr, 1979) and compared to dolls and ‘self-projection’ (Cox, 1977a).

Angle of viewing position relative to the subject also seems to play an important role (Cox 1977b; Fehr, McMahon & Fehr, 1982; Nigl & Fishbein, 1974) with positions maximally adjacent to the subject’s viewing position being easiest and position opposite the child hardest. Children were also found to benefit from being allowed to walk around the array prior to the task (Eiser, 1974; Huttenlocher & Newcombe, 1984; Huttenlocher & Presson, 1973). However it is likely that this may simply enable them to recall a previously seen perspective and so not construct a new perspective by tapping into conceptual spatial knowledge. However, Shantz & Watson (1971) did find that allowing the child to move around to the new position whilst the array was shielded from view lead to greatly improved performance by four to six year olds suggesting, as in previous studied of Object Mental Rotation compared to Subject Mental Rotation tasks, that young children are capable of spatial transformations. This improvement may be related to changes in external frames of reference, which also have to be considered in standard perspective-taking task (Huttenlocher & Newcombe, 1984).

The characteristics of the stimuli have also been seen to have an effect on levels of ability in perspective taking tasks. Borke (1975) found that performance improved in displays using familiar objects such as animals and houses that had identifiable fronts whereas Matthews, Beebe & Bopp (1980) report a small improvement in performance if children are allowed to play with the materials prior to the task. However this was not found to be statistically significant. The number of items in the array and the type of transformation that the child must perform are also
important. Although there is evidence that single object arrays are easier than three object arrays in both model-rotation and picture selection tasks (Fishbein, Lewis & Keiffer, 1972), other studies have failed to yield an effect (Brodzinsky et al., 1972; Liben, 1978; Minnigerode & Carey, 1974; Nigl & Fishbein, 1974). It may be that once the number of objects is more than one, any subsequent objects provide only redundant information. Evidence suggests, as previously mentioned that left-right relationships present greater difficulties than Near-Far ones (Eiser, 1979; Hoy 1974; Laurendeau & Pinard, 1970).

Children’s performance may also be influenced by the manner in which the child is required to respond. Perspective-taking tasks appear to be difficult only in certain formats. Newcombe & Huttenlocher (1992) suggest previous research involving perspective-taking has often required children to select a picture showing a display as it would be seen from a different vantage point. However, this method frequently involves a conflict between the child’s frame of reference and that from the other viewpoint which must be imagined. They state that this conflict is problematic for both adults and children and that, in situations where this conflict is absent i.e. by asking children to answer questions (item questions) about the relative positions of objects, without reference to the surrounding environment, performance of children as young as three is well above chance levels.

Piaget’s task involved three modes of response. Nigl & Fishbein, 1974 found that offering models rather than picture aids performance. Fehr, Lapsley, Enright, McMahon & Ackerman (1983) found that performance comparing pictures with a three-dimensional stimulus was poorer than that comparing with a two-dimensional stimulus and suggest that the cognitive demands of comparing a three-dimensional stimulus with a two-dimensional representation reduce the likelihood of correct responding. Fishbein, Lewis & Keiffer (1972) suggest that if pictures are used, a task that demands the comparison of several pictures may be too demanding for younger children. If the choice of pictures includes only possible views, however, then the correct picture can be selected on the basis of only one picture within the array. This is true also of model rotation tasks (Newcombe, 1989) and studies suggest that these lead to success at earlier ages (Borke, 1975; Fishbein et al., 1972; Rosser, 1983).

Huttenlocher & Presson (1979) and Newcombe & Huttenlocher (1992) used questions about the objects in an array to gain information about children’s perspective taking and Huttenlocher & Presson (1979) found that when eight year
olds were asked about what they would see from different vantage points they gave eighty percent correct responses compared to forty-four percent correct using various models of the display. Performance by three, four and five year olds also exceeded chance using the item questionnaire (Newcombe & Huttenlocher, 1992) and at five years, eighty-two percent of responses to item questions were correct as opposed to forty-three percent on appearance (picture-based) questions.

In addition to factors concerning the attributes of the child, the task and the response, training on perspective-taking tasks as also been shown to lead to improved performance. Miller, Boismier & Hooks (1969) found slight improvement in perspective-taking after six sessions of training as did Cox (1977c) after twenty training sessions. In the case of the children in Cox’s (1977c) study this improvement persisted at a seven-month follow-up. Both studies focused on as many aspects of the perspective-taking task as possible, however a subsequent study by Silverman (1986) suggests that feedback concerning the correctness of responses alone lead to significant improvements in performance and that instruction on coding the array was detrimental to performance in the absence of feedback.

Research subsequent to Piaget & Inhelder’s (1956) classic paper involving the three-mountains task suggests that to some degree Piagetian theory underestimates the cognitive abilities of young children. Research on Object Mental Rotation tasks and Subject Model Rotation versions of perspective taking tasks shows these tasks can be completed with relative ease by even fairly young children. What is apparent however is that young children may be influenced by factors in these tasks that are not problematic to older children. Issues such as conflict between internal and external frames of reference and the desire for intellectual realism are key. Model rotation tasks maintain internal spatial relationships and so may be less cognitively demanding for the child. It has been suggested that the child’s ability to perform various perspective-taking tasks is dependent upon the acquisition of various rules for knowing what another person sees in general and also the computational rules for knowing what one person sees in particular (Flavell, Omanson & Latham, 1978). Knowledge that others have different views to one’s self reflects the first of these rules whereas ability to correctly identify what they see in its entirety reflects the second.
The ability to coordinate dimensions

The study of children’s ability to use coordinate reference systems is embedded in Piaget & Inhelder’s (1956) account of children’s development of spatial organisation. Piaget & Inhelder (1956) suggest that children’s spatial abilities progress through three stages: topological, projective and Euclidean. According to Piaget & Inhelder, the topological stage involves a knowledge of perspectives and location in qualitative terms such as the enclosure, proximity or relationship to other objects, the projective stage, which emerges during the concrete operational stage of development, involves knowledge of the relationships between several objects, perspective and the relationship of other views, but only in the Euclidean stage, occurring with formal operational thought, is the child able to fully coordinate perspectives and recognize relationships and properties in metric terms. According to Piagetian theory children’s lack of a Euclidean coordinate system is demonstrated by their inability to make distance judgments and the use of topological rather than configurational knowledge in locating objects in addition to the egocentrism demonstrated by an inability to identify another’s viewpoint or perspective.

Piaget & Inhelder (1956) suggest that the emergence of a Euclidean coordinate system is demonstrated by the ability to appreciate naturally occurring horizontals and verticals in the environment. An absence of these abilities is shown in young children’s inability to successfully complete Piagetian tasks such as the water jug task which requires children to indicate the water level on a tilted jug and the plumb line task which requires them to draw a plumb line from an angled object. The inability of young children to draw vertical chimneys on sloping roofs has also been proposed as a reflection of this. However, some adults make errors on Piagetian water level and plumb line tasks (Harris et al., 1975; Liben, 1978; Signorella & Jamieson, 1978; Thomas et al., 1973; Barsky & Lachman, 1986; Liben & Golbeck, 1984; Meehan & Overton, 1986) and both children and adults perform better on tasks using alternative procedures (Liben & Golbeck, 1980; Mcgillicudy-De Lisi et al. 1984). It is also thought that errors in children’s drawings are due to perpendicular bias rather than an inability to appreciate naturally occurring horizontals and verticals (Perner, Kohlmann & Wimmer, 1984).

As a test of children’s ability to use Euclidean geometry Piaget, Inhelder & Szeminska (1960) presented children with tasks that involved the location of points in one-, two- or three-dimensions. In the two-dimensional task children were presented
with a sheet of paper with a point marked on it and asked them to mark the point in space on a blank sheet of paper. The children were supplied with a ruler, stick, strips of paper and lengths of thread. They found that children below the age of eight were unable to succeed at this task. In stage one, up to about four years six months, the children simply estimated the point visually and only at the age of around eight years nine months do they spontaneously measure the distance along two dimensions.

Carlson (1976) also examined the ability of children between the ages of seven and thirteen to locate points in one-, two- and three-dimensional space. Children were again required to locate a point in one, two or three dimensions and were supplied with a variety of measuring instruments to enable them to do so. Children were interviewed as they completed the task and their responses were classified according to Piaget’s scoring stages as defined by Brearly & Hitchfield (1969). To pass any task the subjects had to score at the stage three level which is characterised by ‘those who, by correct response and explanation, can justify their answers and show they have attained a steady understanding of the concepts involved’. As in Piaget’s analysis of group performance, a particular age group was thought to understand the concepts if more than seventy-five percent of the group passed the task. Carlson found that one-dimensional tasks were easier than two-dimensional tasks, which were easier than three-dimensional tasks. Subjects were capable of completing the one-dimensional task by age eight, the two-dimensional task by age ten and the three-dimensional task by age twelve. These findings disagree with those of Piaget & Inhelder who suggest there is no time lag between two-dimensional and three-dimensional measurement. Carlson’s results also run contrary to those of Piaget who suggests that at around the age of nine there is a decisive turning point in the development of spatial concepts. This would imply a developmental shift in ability to respond with stage three answers at this age, however Carlson’s results suggest a continuous progression through the age grades, suggesting this is not so.

Piaget & Inhelder’s (1960) tasks have been criticized for being highly complex as the children had to construct their own grid with the materials supplied and may have lacked not only the motor skills and coordination necessary to successfully complete the task but also the awareness of and the ability to express the appropriate strategies (Matthews 1992). Further work such as that by Huttenlocher, Newcombe & Sandberg (1994) suggests that children as young as sixteen months are able to locate a hidden object in a sandbox in the absence of topological cues although
in this task they were only required to attend to one dimension. However they do state that, rather than relying on Euclidean coordinate systems, a radial coordinate system, based on angle and distance from a reference point is preferred. Work with both adults and children supports this (Engebretson & Huttenlocher, 1996; Laeng, Peters & McCabe, 1998; Newcombe & Liben, 1982; Sandberg, Huttenlocher & Newcombe, 1996; Newcombe et al., 1999; Tada & Stiles, 1996). This preference for a non-Euclidean reference system does not however imply that a Euclidean reference system is beyond the capabilities of children in situations where such a system is called for (Crawford, Regier & Huttenlocher, 2000; Huttenlocher, Hedges & Duncan, 1991). Young children of three and four years have also been shown to demonstrate reasonably accurate ability to scale distances (Huttenlocher, Newcombe & Vasilyeva, 1999).

There is substantial research to counter Piaget’s suggestion that young children below seven or eight do not have the abilities to use vertical and horizontal coordinate systems. However because of the reliance on tasks that maximize children’s performance, many of these involve both perceptual and conceptual components.

Somerville & Bryant (1985) found that four to six year olds can extrapolate lines on horizontal and vertical axes to a meeting point. Children were shown a board that covered two orthogonally placed rods, the ends of which were visible, and asked to locate at which of four points the rods met. In a later experiment they were also shown two orthogonally placed figures and asked to identify where they would meet if they both walked forwards. Almost all five to six year olds and over half the four year olds performed at a level above chance. Similarly Bremner, Andreasen, Kendall and Adams (1993) found four year olds were proficient at interpreting orthogonally placed markers under certain line-of-sight conditions. However in other, more abstract situations, the performance of four year olds was often only at the level of chance whereas the performance of older children of five and six was superior (Somerville & Bryant 1985; Blades & Spencer 1989, Experiment 1). In these studies the coordinate system was marked/provided and it may well be that these tasks were tapping into perceptual spatial ability rather than conceptual ability.

Bryant & Somerville (1986), however, tested six and nine year olds’ ability to coordinate information on two axes and found children do not find spatial demands of graphs problematic, there was no suggestion from their results of an inferior grasp of
Euclidean spatial relationships below nine, although six year olds were found to be less accurate than nine year olds.

In the field of research into children’s ability to coordinate dimensions there is a distinction between two types of task. One task is that of interpretation where a child is given a set of Euclidean coordinates and has to locate the correct point in space on the basis of these. This usually takes the form of retrieving some hidden object. A construction task on the other hand requires the child to give the correct coordinate dimensions for a point in space that is already known. The majority of research has focused on the child’s ability to interpret Euclidean coordinates and locate an object or location. Little research however has been carried out regarding the child’s ability to construct coordinates for a given location and it can be argued that the ability to construct Euclidean coordinates may provide stronger evidence for spatial knowledge (Lidster & Bremner, 1999). Blades & Spencer (1989, Experiment 3) used a grid of nine sunken squares and a set of colour coded grid reference cards to test children’s ability to select the correct coordinate reference and found that on the whole performance on a construction task equal to that on an interpretation task. However not only were the mean scores higher for the construction task in the two older age groups but also the proportion of children scoring above chance levels was greater for these two groups. Their task however provided cards with a choice of possible grid references and so the children’s responses were constrained by these.

Lidster & Bremner (1999) compared children’s performance on an interpretation task and a construction task using a technique akin to Breimier et al.’s (1993) arrow task. They found not only a significant main effect of condition with performance on the construction task superior to that on the interpretation task but also that there was a significant main effect of order with a carry over effect between construction and interpretation tasks.

There is a wide body of evidence to suggest that young children are neither as egocentric nor as spatially incompetent as Piaget and his colleagues propose. Children as young as two years old are aware that another’s view is not the same as their own although their ability to compute what this view consists of may not be fully developed. Children as young as five years old seem able to respond to questions relating to the positions of objects relative to another’s viewpoint when there is no conflict between internal and external frames of reference and although there are various task factors which affect the ease with which children can complete
perspective-taking tasks, there are signs of early competence. Children's ability to coordinate two dimensions has certainly been demonstrated at an early age. Although some errors may prevail and completion of complex abstract tasks such as those devised by Piaget, Inhelder & Szeminska (1960) seem problematic, there is little evidence to support the notion that the young child has no grasp of projective or Euclidean coding. Young children, well below the age predicted by Piaget and his colleagues, are capable of successfully coordinating two dimensions when suitable tasks are employed. However the problems encountered in completing tasks may give an insight into the developmental processes required to develop a complete understanding of Euclidean concepts.

Aims of the current research

The aim of the current research is to resolve the issues raised by previous research into young children's ability to use coordinate dimensions/references. Research cited above suggests that there are differences in performance on coordinate dimension tasks both between interpretation and construction tasks and between different conditions of these tasks. The primary aim of this research is to investigate the factors responsible for these differences in performance and to observe developmental trends with regard to these factors.

Although a substantial number of children have been shown to be capable of both constructing and interpreting coordinate references at levels above chance, errors are still prevalent. A second aim of this research is to determine to what degree these errors can be accounted for according to the existing theoretical frameworks.

With these aims, the current research investigates the factors determining success and failure on tasks involving the use of Euclidean coordinates. The following chapters report a series of six related experimental studies designed to resolve these issues.
PART TWO

Empirical Studies

Overview

The ability to use a coordinate reference system is a key component to many activities used in both everyday and educational settings. The concept of Euclidean space is thought to be a key element in spatial knowledge of the environment and wayfinding. In addition children between the ages of seven and eleven, are introduced to the concepts of maps and grids and also exposed to the need to read off against two axes in mathematics classes involving data representation. In keeping with a Piagetian point of view, these concepts are not introduced to younger children. It is possible however that these children might benefit from early introduction to such skills both in an educational context and in the development of their environmental knowledge. Recent research shows that a substantial number of young children between four and six appear to be able to correctly construct and interpret Euclidean coordinates. However, performance on these tasks is far from error free. Performance differs according to whether children complete construction or interpretation tasks as well as according to the position of the location cues relative to the target object. In addition carry-over effects have been observed.

The following studies aim to investigate the reasons for these differences in performance. Research cited in the previous chapters has suggested that although young children may be more spatially advanced than Piaget & Inhelder (1956) propose, there is evidence for developmental progression ability on spatial tasks. Previous research into children’s construction and interpretation of spatial coordinates suggests that there may be differences in performance between these tasks (Lidster & Bremner, 1999) and also according to age (Lidster, 2002). The reason for these differences has not been fully explored and may have important implications both theoretically and educationally. Currently children are not introduced to aspects such as graph work until around the age of seven or eight. Drawing on previous research by Lidster & Bremner (1999) and Lidster (2002), the purpose of the following empirical studies is to explore the nature of children’s ability to construct and interpret Euclidean coordinates.
coordinate dimensions. The methods employed will involve both comparison of performance on these tasks under a variety of conditions thought to affect performance and analysis of errors on these tasks. It is thought that detailed examination of errors in completing these tasks will provide an insight into the underlying mechanisms of coordinate construction and interpretation.

Experiments One, Two and Three all aim to investigate the effects of age and differences in scoring criteria on performance in spatial coordinate tasks. Experiment One aims to investigate one possible cause for the advantage of construction over interpretation and to explore age effects on this ability whilst at the same time assessing the degree to which scoring criteria may affect the conclusions drawn. Experiment Two looks at age effects in accuracy on the interpretation task, whereas Experiment Three compares children’s performance on an interpretation task using two- and three-dimensional materials according to two scoring criteria.

It is thought that the nature of response on construction and interpretation tasks may bias or influence children’s responses on these tasks. Therefore Experiments Four, Five and Six aim to investigate performance on construction and interpretation tasks when task demands are changed. Experiment Four investigates children’s performance on construction and interpretation tasks when the possible distracting items are removed and Experiment Five looks at the effect of scale on this task. Finally Experiment Six explores children’s use of coordinates using a touch-screen paradigm.
Chapter 2: Study One

Comparison of performance on simultaneous versus serial construction task.

Introduction

The advantage of construction tasks over interpretation tasks.

Whereas there is a considerable body of research concerning children’s ability to interpret coordinate dimensions, little has been done to investigate children’s ability to construct coordinates for a given location. Exceptions to this are the work of Blades & Spencer (1989, Experiment 3) and Lidster & Bremner (1999). The results of these studies are equivocal, the former suggesting that both construction and interpretation tasks are of equal difficulty and the latter suggesting that differences exist in children’s ability to interpret and construct coordinate dimensions.

Blades & Spencer (1989) conducted a series of experiments aimed at testing young children’s ability to use a coordinate reference system. In their interpretation condition four to six year old children were required to select the correct square from a four by four grid of sunken squares, having been given a card showing either alphanumeric or colour coded grid references for that square. In the construction condition Blades & Spencer (1989, Experiment 3) used a grid of nine sunken squares and a set of colour coded grid reference cards to test four to six year old children’s ability to select the correct coordinate reference for a given square. They found that, on the whole performance on a construction task was equal to that on an interpretation task suggesting the construction and interpretation tasks are equal in difficulty. Although they found similar numbers of children scoring above chance level on the construction task as Lidster and Bremner (1999), levels of performance on the interpretation task are superior to those found by Lidster & Bremner. This may be due to methodological differences between the studies.

Lidster & Bremner (1999) compared the performance of eighty children between the ages of four years six months and five years five months on interpretation and construction tasks. The interpretation task took the form of a treasure hunt game where the position of two orthogonally placed arrows pointed to the location of a cardboard teddy which had been hidden under one of four cups whilst the child was
not looking. The child's task was to locate which cup the teddy was hidden under by imagining lines extending from the arrows so that the cup where teddy was hiding would be where these lines "bumped into each other". The construction task took the form of the child watching where the experimenter hid the teddy and then placing the arrows in such a way that they indicated to a third person where teddy was hiding.

Lidster & Bremner categorised the trial types into Near-Near (hiding place close to both arrows), Far-Far (hiding place far from both arrows) and Near-Far (hiding place near to one arrow but far from the other) and counterbalanced the order in which the conditions were performed.

Using a simple two by two array of cups Lidster and Bremner found, not only that young children are capable of constructing and interpreting orthogonal cues to location, but also a significant effect of condition. Overall performance on the construction condition was superior to that on the interpretation condition. Approximately fifty percent of children in the interpretation condition scored at above chance levels compared with seventy-five percent in the construction condition. They also found a significant carry over effect with performance on the interpretation task showing a greater number of correct responses when preceded by a construction task compared to when preceded by an interpretation task. In addition a significant main effect of trial type was also evident with performance on Near-Near trials being superior to that on Near-Far trials, which was in turn superior to that on Far-Far trials at all levels of the task. However an effect of group (construction-construction, construction-interpretation, interpretation-construction or interpretation-interpretation) was only present in the Far-Far condition suggesting that performance on the Far-Far condition in the interpretation condition is a major source of variation in performance.

The present experiment aims to address issues brought about by Lidster & Bremner's (1999) study. One possible explanation, suggested by Lidster & Bremner, for the advantage of the construction task over the interpretation task is that children's performance reflects more direct engagement in the construction task, allowing the principles of the task to become more apparent. Another explanation is that during the construction task the children are not required to move the pointers simultaneously and so are able to attend to only one coordinate at a time. Although Lidster & Bremner (1999) argue that the fact children do adjust both arrows indicated that they are adhering to Euclidean principles, it can be argued that the construction task can be
completed without any necessity to use both coordinate dimensions simultaneously. In the construction task the coordinate can be constructed simply by lining up each of the markers in turn whereas this is not possible in the interpretation task as identification of the correct location requires taking both markers into account simultaneously. This could result in the construction task being easier. The introduction of explicit instructions to move the pointers at the same time would ensure that the two dimensions were being coordinated simultaneously.

**Research on bi-manual tasks**

Motor constraints may have a profound effect on any task involving simultaneous limb movements and research on bi-manual tasks in adults suggests that temporal coupling of movements may occur in such circumstances. Kelso, Southard & Goodman (1979) found that, in tasks involving lateral movements from the body's midline and also those involving forwards and backwards movements to and from the body's midline, that subjects initiate and terminate two handed movements simultaneously even though those hands may be moving different distances or aimed at different sized targets. Movement times are determined by the most difficult target, that is the target which combines greater movement amplitude with small target size. Franz, Zelaznik & McCabe (1991) also found that in bimanual tasks the two hands were not only closely temporally locked but were spatially constrained such that when different movements are required from each limb then the output from each limb becomes more like that from the other. However Swinnen et al., (1998:1990) suggest that temporal synchrony is lessened when the required movements differ in their trajectories.

Though little research has been carried out regarding temporal synchrony in children it is reasonable to expect that such a phenomenon may also operate in children and that perhaps this may affect performance on these tasks. In particular it could lead to poorer performance on tasks requiring simultaneous movement of the hands over different distances (as in Near-Far and Far-Near trials in this study) and to the facilitation of trials involving equidistant hand movements in the simultaneous condition (such as Near-Near and Far-Far trials). If temporal coupling is affecting performance on this task we could expect performance on Far-Far trials and Near-Near trials to be superior in the simultaneous condition. It is also possible that the
errors occurring in the simultaneous condition are likely to reflect this synchrony of movement.

The subdivision of space

Huttenlocher, Newcombe & Sandberg (1994) suggest that children as young as four years of age are able to subdivide space categorically and that developmental differences may occur in the ability to subdivide space. They state that spatial location is coded increasingly hierarchically with age. This concept of developmental differences is supported by the findings of Bryant & Somerville (1986) who found that six year olds were likely to be less accurate than nine year olds in their ability to locate the exact location indicated in their study. Lidster (2002) also found that older children showed a greater number of correct responses than younger children using the same construction and interpretation tasks in earlier work (Lidster & Bremner, 1999).

Sandberg, Huttenlocher and Newcombe (1996) suggest that there are developmental constraints that determine the number of sectors that children divide space into and that subdivision of space becomes increasingly fine-grained with age. In the work of Lidster & Bremner (1999) simple two by two arrays were used and Lidster & Bremner’s (1999) design allowed a response to be classified as correct even if the intersection of the two markers did not lie within the area of the cup. In order to explore differences in accuracy amongst the children and any possible effect this method of scoring may have had, an alternative method of scoring was introduced by subdividing each of the quarters of the square into a three by three grid, resulting in a division of the whole area into a six by six grid. The centre square of each quarter of the grid held the cup and, in comparison to both Lidster & Bremner’s (1999) and Lidster’s (2000) criteria, responses were only considered correct if the intersection point of the imaginary lines extending from the pointers lay within the area of the cup (see Figure 2.1).

It was predicted that children would score fewer correct responses according to this revised scoring system. In addition the present study also aims to investigate developmental changes in the accuracy of children’s responses by increasing the age range of the sample relative to that of Lidster & Bremner (1999). The revised scoring system should reveal any differences in accuracy between the older and younger children. Specifically, younger children would be expected give less accurate
responses than older children and, as a result, differences between scores according to the two criteria would be greater for the younger children.

Figure 2.1 – Position of imaginary lines dividing area into six by six grid, target is in central square of quadrant.

Sex differences in spatial tasks
There is substantial evidence for a male advantage in early childhood on spatial tasks and that these are influenced by the method of presentation and the nature of the environment (Matthews, 1992). However previous studies of young children’s use of coordinate dimensions have failed to find any evidence of sex differences (Blades & Spencer, 1989; Bremner, Andreasen, Kendall & Adams, 1993; Somerville & Bryant, 1985; Lidster, 2002). It was predicted that sex differences would not arise in the present study.

Aims of this study
Research by Lidster & Bremner (1999) has highlighted differences in young children’s performance between construction and interpretation of coordinate dimensions. It is possible that the requirement to integrate information from two dimensions at once during the interpretation condition may be the reason for poorer performance on this task compared to the construction task that does not have this requirement. One way of investigating this is to make explicit the instructions to move both pointers simultaneously to ensure both dimensions are being coordinated.
simultaneously. Performance could then be compared with that of children who were specifically instructed to only consider one dimension at a time. If Lidster & Bremner’s suggestion is correct we would expect superior performance in the construction task where children are instructed to move the pointers sequentially compared to those who are instructed to move them simultaneously.

In summary, the aims of this study are to investigate the effects of serial versus simultaneous positioning of the pointers on task performance by having two groups of children perform a task involving the construction of spatial coordinates under serial and simultaneous conditions. At the same time the experiment aims to investigate the effects of age on accuracy and to what extent results are affected by the use of different criteria for scoring responses. Also of interest are differences in performance according to trial type as noted in Lidster & Bremner’s (1999) study.

In particular it is predicted that there will be a significant effect of condition on children’s ability to construct coordinate dimensions. Children performing under the serial condition should give a greater number of correct responses than those performing under the simultaneous condition. We also predict that there will be a significant effect of age upon performance with older children giving a greater number of correct responses. Responses from older children should show a greater degree of accuracy than those of younger children.

Method

Participants

Eighty-four children between three years ten months and five years eleven months participated in this study (mean age four years ten months). As the study was to be carried out in the classroom permission was sought form both parents and teachers (see Appendix 1). The children were randomly assigned to two groups such that the mean ages of the two groups were comparable. The children were taken from the nursery, reception year and year one of a local primary school. The school was in a predominantly white, middle-class area of Surrey. The children were further divided into two age groups on the basis of whether they were above or below the mean age of four years and ten months (Mean age 4 years 4 ½ months, n=41, range = 3 years 10 months - 4 years 10 ½ months for the younger age group. Mean age 5 years 4 ½ months, n=43, range = 4 years 11 months - 5 years 11 months for the older age group).
Materials

Four identical Styrofoam cups, 3 cm in height and 5 cm in diameter served as hiding locations and were placed with their centers approximately 25 cm apart on a sheet of white cardboard measuring 50 cm x 50 cm which was mounted in one corner of a square of Medium Density Fibreboard (MDF) measuring 60 cm x 60 cm, leaving room along two adjacent sides for two wooden pointers on a sliding mechanism (see Figure 2.2). These were used as orthogonal markers to the correct location. The sliding mechanism was marked in an unobtrusive fashion so as to enable the experimenter to classify the child’s responses easily. The same card teddy approximately 4 cm in height was used as a hiding object in each trial. The apparatus was placed on the floor to enable the child to look down on it.

Figure 2.2: Apparatus used in the current study, a teddy bear was hidden beneath one of the four upturned cups.

Design

Experiment One consisted of a coordinate construction task. A multivariate design was undertaken so that the effects of several independent variables could be explored simultaneously. One within-participant variable investigated was Pointer position in which there were four levels relating to the initial start position of the pointers at the beginning of the trial relative to the child (Near-Right, Near-Left, Far-Right and Far-Left). A second within-participant variable was target Position in which there were also four levels and which relates to the position of the target relative to the child (Near-Right, Near-Left, Far-Right and Far-Left). In addition a further within-participants variable was manipulated, that of Trial Type. There were
four levels of Trial Type (Near-Near, Near-Far, Far-Near and Far-Far) which corresponded to the position (whether in the near quadrant or the far quadrant) of the target relative to the pointers on the two axes. Each level of Trial Type contained one trial with the target position in each of the four quadrants and the start position of the pointers in each of the four corners. The between-participant variables investigated were Age (two levels; above or below the mean of four years and ten months old) and Condition which referred to whether the participants were required to respond simultaneously, by moving both hands at the same time, or in a serial fashion moving one hand and then the other, thus there were two conditions of the construction task included in the experiment and each child only completed one condition.

The first group was given a series of trials equivalent to Lidster & Bremner’s construction task where they had to coordinate two pointers in serial order to point to the location of an object hidden beneath one of four plastic cups by moving first one pointer then the other. There was no constraint upon which they moved first. The second group were given the same task but had to coordinate the pointers simultaneously by holding one pointer in each hand and moving them at the same time. The position of the pointers on each trial was manipulated by rotating the board giving rise to four trials in each of the four different positions each corresponding to a different trial type (Near-Near, Near-Far, Far-Near, Far-Far). The dependent variable in this experiment was number of times the participants correctly constructed the coordinates over a course of 16 trials. Two criteria were used to score these responses. The Correct Quadrant criterion classified a response as correct if the intersection of two imaginary lines drawn from the pointers fell within the same quadrant as the target whereas the Absolute Accuracy criterion required the intersection to fall within the central area that held the target cup in order to be classified as correct.

Figure 2.3: Different trial types- target position shown in black
Procedure

Each child was tested individually in a quiet corner of the classroom. Before the task it was explained to them that they were going to play a game called ‘hide the teddy’ and that the experimenter was going to hide the teddy under one of the upturned cups and that the child had to position the arrows either ‘one at a time’ or ‘both at the same time, one in each hand’ so that they both pointed to where teddy was hiding. During the explanation the experimenter hid the teddy once as for a Far-Far trial, lined up the pointers correctly and traced imaginary lines with her finger and it was explained that the child had to place the pointers so that imaginary lines would meet where teddy was hiding (‘See, if you were to draw a straight line out from the pointers, where they bump into each other, that’s where teddy is hiding...look there he is!’) and lifted up the cup to reveal teddy. The child was then given an opportunity to practice moving the pointers either simultaneously or sequentially according to which condition they were in. During this practice they were told that they were permitted to lean or kneel on the board if they needed to.

The introduction was followed by sixteen trials. These sixteen trials represented all possible combinations of the four different positions of the hiding place (front-left, front-right, rear-left, rear-right) with the four different trial types as defined by the distance on each dimension from the pointer (Near-Near, Near-Far, Far-Near, and Far-Far). In Near-Near trials the hiding place was near to the markers on both horizontal and vertical dimensions. In Far-Far trials the hiding place was far from the pointers on both dimensions. In Near-Far trials the hiding place was near to the vertical marker but far from the horizontal marker. In Far-Near trials the hiding place was near to the horizontal marker but far from the vertical marker. The trials were presented in a randomised sequence.

The child was instructed to ‘watch very carefully while I hide teddy’ and the experimenter hid the teddy under one of the cups. The experimenter then asked ‘can you remember where he is?’ and if the child answered yes, either verbally or by nodding, they were told to ‘show me with the pointers then’. If the child answered ‘no’, the cup was lifted to show where the teddy had been hidden and then the trial continued. The child then moved the pointers to point to where teddy was hiding. If necessary they were reminded to complete the task either by moving the pointers ‘one at a time’ or ‘both at the same time’. When the child had finished moving the pointers the experimenter asked if they were ready and picked up the cup nearest to the point
indicated by the child’s positioning of the pointers with the words ‘is he there?’ and if so replied ‘yes’. If the pointers pointed to the wrong cup, the teddy was then retrieved from his hiding place with the words ‘there he is!’ This procedure was repeated for all sixteen trials which were linked by the phrase ‘this time teddy’s/he’s going to hide here’

Results

The responses were recorded by marking the position that the arrows pointed to on a six by six grid visible only to the experimenter. Each of the quadrants for the four possible locations being further subdivided into a three by three grid. This allowed responses to be analyzed later both in terms of the number of correct responses and in terms of types and patterns of errors. Errors were subsequently coded in terms of position on the horizontal and vertical axes relative to the target. For each child, separate scores reflecting the number of correct responses, were taken for each trial type using both the Lidster & Bremner (correct quadrant) method and also for absolute accuracy using the modified six by six method.

Table 2.1 Mean scores per trial type out of four (s.d. in brackets) according to original, correct quadrant, scoring system (CQ) and revised, absolute accuracy, scoring system (AA)

<table>
<thead>
<tr>
<th>Trial Type</th>
<th>Near-Near</th>
<th>Near-Far</th>
<th>Far-Near</th>
<th>Far-Far</th>
<th>Total (/16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition 1 (Serial)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQ</td>
<td>3.68(0.79)</td>
<td>3.32(1.06)</td>
<td>3.39(0.89)</td>
<td>3.22(0.94)</td>
<td>13.59(2.81)</td>
</tr>
<tr>
<td>AA</td>
<td>3.20(1.75)</td>
<td>2.54(1.63)</td>
<td>2.37(1.67)</td>
<td>2.17(1.70)</td>
<td>10.27(5.41)</td>
</tr>
<tr>
<td>Condition 2 (Simultaneous)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQ</td>
<td>3.42(1.12)</td>
<td>2.74(1.27)</td>
<td>3.37(1.02)</td>
<td>3.56(0.63)</td>
<td>13.07(3.31)</td>
</tr>
<tr>
<td>AA</td>
<td>3.12(1.26)</td>
<td>2.21(1.58)</td>
<td>2.67(1.43)</td>
<td>2.21(1.63)</td>
<td>10.19(5.03)</td>
</tr>
<tr>
<td>Both conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQ</td>
<td>3.55(0.97)</td>
<td>3.02(1.20)</td>
<td>3.38(0.96)</td>
<td>3.39(0.81)</td>
<td>13.32(3.07)</td>
</tr>
<tr>
<td>AA</td>
<td>3.15(1.20)</td>
<td>2.37(1.60)</td>
<td>2.52(1.55)</td>
<td>2.19(1.65)</td>
<td>10.23(5.19)</td>
</tr>
</tbody>
</table>
Data were analysed using two criteria, one according to correct quadrant and another for absolute accuracy. Table 2.1 shows the number of correct responses by condition and trial type using both scoring systems.

Using the criterion of responses within the correct quadrant, the probability of responding correctly by attending to only one marker is .50 since there are only two locations the child’s response could be classified as falling within. Therefore the children’s total correct responses were compared to a binomial distribution based on the probability of .50 of correctly responding. It was found that approximately seventy-nine percent of the sample scored twelve out of sixteen or better (binomial probability, p<0.05). Using the second criterion, that of absolute accuracy, the probability of responding correctly by attending to only one marker is 1/6 or 0.167 as their response can be classified as pointing to one of six locations. Based on a probability of 0.167 of responding correctly by attending to only one marker, approximately seventy-three percent of the children scored six or more correct answers (binomial probability, p<0.05).

Preliminary screening of the data revealed no significant sex differences in mean scores on any trial types and so data analysis did not include gender.

In order to ascertain the effect of the two different scoring criteria on the results, two 4-factor Position (4) x Pointer (4) x Age (2) x Condition (2) ANOVAs, one for each of the scoring criteria were carried out with repeated measures on the first two factors. Analysis of the data showed there was no significant effect of condition according to either the correct quadrant or the absolute accuracy criterion. (F (1, 80) = 0.875, p>0.05 and F (1, 80) = 0.062, p>0.05 respectively). A significant main effect of age was present under both the correct quadrant and the absolute accuracy criterion (F (1, 80) = 8.82, p<0.05 and F (1, 80) = 13.15, p=0.001 respectively). In addition, scores according to the correct quadrant criterion were significantly higher than those according to the absolute accuracy criterion (t=8.63, p<0.001, one- tailed) and younger children showed a greater difference in scores according to the two scoring systems than older children. Younger children scored on average eight correct answers according to the absolute accuracy criterion and twelve correct according to the correct quadrant criterion in comparison to older children who scored on average twelve and fourteen correct respectively (t=2.91, p<0.005, one-tailed). This suggests that children’s accuracy improves with age (see Figure 2.4).
A significant main effect was found for pointer position according to the absolute accuracy criterion \((F(3,240)=3.86, p<0.05)\) but not for the correct quadrant criterion. Further analysis of this result suggests that performance is significantly poorer according to this criterion on trials where the pointers are situated on the far side of the board to the child \((t=3.172, p=0.001\), one-tailed\). (See Figures 2.5a and 2.5b).

**Figure 2.4:** Mean number of correct responses (out of 16) by two age groups using two scoring criteria

![Mean number of correct responses (out of 16) by two age groups using two scoring criteria](image)

In addition to these main effects, significant Position x Pointer interactions were found according to both scoring criteria \((F(9,240)=4.21, p<0.001\) for the correct quadrant criterion and \(F(9,240)=10.47, p<0.001\) for the absolute accuracy criterion). As the distance between the pointers and the target cup on each dimension (trial type) depends upon the position of the cup on the board (target position) and the position of the pointers (pointer position) it was felt that the Position x Pointer interaction could be explained as due to Trial Type. Consequently two three-factor Trial Type \((4)\) x Age \((2)\) x Condition \((2)\) ANOVAs, with repeated measures on the first factor, were carried out, one for each scoring system and a main effect for trial type was apparent for both scoring criteria \((F(3,240)=19.61 p<0.001\) for absolute accuracy and \(F(3,240)=8.23, p<0.001\) for correct quadrant).
Figure 2.5a: Mean number of correct responses (out of 4) according to pointer position using the Absolute Accuracy scoring criteria

Figure 2.5b: Mean number of correct responses (out of 4) according to pointer position using the Correct Quadrant scoring criteria
A main effect for age ($F(1, 80) =13.25, p<0.001$) (absolute accuracy); $F(1, 80) =8.82, p<0.005$) (correct quadrant) was also found. Trial Type was shown to interact with Age ($F(3, 240) =3.08, p<0.05$) and Condition ($F(3, 240) =6.52, p<0.001$) when using the correct quadrant criteria. Older children performed significantly better on Near-Far trials and Far-Near trials than younger children.

In addition to dealing with correct responses, it was felt that it was important to look at the nature of the errors children make. Analysis of the types and patterns of errors children make in different situations could provide valuable insights into the main effects discovered, and in particular into the interactions between variables. It was felt that error patterns may reflect children’s strategies for completing the task.

Participants’ responses were coded according to the degree of left-right and Near-Far error. The majority of incorrect responses (280/474=59%) contained errors on only 1 coordinate dimension. Figure 2.6 shows the frequency of different error types under the two conditions.

Data were also collected regarding the magnitude of these errors and error scores were compared for Near-Far and Far-Near trials. Results of t-tests show that for both these trial types the mean error was significantly larger in the dimension where the coordinate marker was far from the target ($t=7.42, p<0.001$ for Near-Far trials, $t=-4.46, p<0.001$ for Far-Near trials). Analysis of the types of errors made in each trial under each condition also demonstrated that the majority of errors involved overshooting the target on either dimension (63%) and that these types of errors were more frequent in the simultaneous condition as opposed to the serial condition (176/474 compared to 124/474). The binomial probability of such a distribution was calculated and found to be significant ($p<0.005$).

Further binomial probability analysis of the number of errors occurring in the simultaneous and serial conditions revealed significantly more errors involving overshooting the target in both the horizontal and vertical dimensions in the simultaneous condition as opposed to the serial condition ($72:35, p<0.0005$, 2-tailed) (see Figure 2.6).
The results of this study suggest that the majority of children between the ages of three years ten months and five years eleven months are capable of constructing orthogonal cues to the location of objects. These findings confirm those of previous researchers in this area (Lidster & Bremner, 1999; Blades & Spencer, 1989). The results also demonstrate that children are equally capable of doing so under simultaneous and serial conditions. No significant difference was found in the number of correct responses given by children in these two conditions. This leads us to conclude that the construction task in Lidster and Bremner's (1999) study is not facilitated due to the requirement to focus on only one dimension at a time, as doing so does not improve performance on construction tasks when compared to such tasks where the child has to focus on both dimensions at once. This suggests that the advantage children displayed in Lidster & Bremner's construction task may be due to some other factor. One suggestion put forward by Lidster & Bremner for their results is that children may be more directly engaged in the construction task and that the principles may be more apparent than when the arrows have already been placed. In
Lidster & Bremner’s study success rates on interpretation trials were lower than those in Blades & Spencer’s study and so there is also a possibility that their results may be an artefact of the procedures and materials used. These differ substantially from those of Blades and Spencer (1989) who report no significant difference in performance on construction and interpretation trials. However, their sample was considerably smaller and subdivided into three age groups and these methodological factors may explain this lack of difference. In both the five year olds and the six year olds, mean number of correct responses was greater for the construction condition suggesting that the effect in Lidster & Bremner’s study is not an artefact.

The predicted age effect was in evidence; younger children did indeed score more poorly than older children. This was apparent using both scoring systems and it appeared that not only did older children score more answers in the correct quadrant but also as children get older their responses show greater accuracy as to the location of the target within that quadrant. This would support the idea that there are developmental constraints on the size or number of sectors that children divide space into (Sandberg, Huttenlocher & Newcombe, 1996) and that spatial location is coded increasingly hierarchically with age (Huttenlocher, Newcombe & Sandberg; 1994).

Analysis of the results also revealed an effect due to trial type; however, these effects do not appear to coincide with those found by Lidster & Bremner who found Far-Far trials consistently poorer than other types of trials (Near-Near>Near-Far>Far-Far) in both construction and interpretation tasks. The results of this experiment reveal that although this is true for the serial condition, the simultaneous condition does in fact facilitate correct responding on Far-Far trials, but only in terms of the correct quadrant scoring criteria. It may be that simultaneous movement of the hands facilitates performance on such trials relative to those where a different amount of motor movement is required by each arm/hand when greater accuracy is not a requirement. Kelso, Southard & Goodman (1979) report that there is strong evidence for temporal synchrony in adults performing bi-manual tasks. This synchrony was such that both hands would initiate and terminate movement towards targets virtually simultaneously with movement times therefore being determined by that necessary to reach the further, or more difficult of the targets. If such temporal synchrony were to exist in the task in this study, without the ability to regulate the speed of movement of the two hands then this might result in less accurate responding in simultaneous trials where the amount of movement required by each hand differs (Near-Far and Far-Near...
trials. Such trials would be expected to display errors in terms of overshooting the target on the dimension where the target is nearer to the starting point for the markers. Examination of the different error types on each trial suggest that this indeed is a factor, the majority of errors on Near-Far and Far-Near trials consist of overshooting the target on the near dimension, and these are more prevalent in the simultaneous condition. However this temporal synchrony may not be sufficient to explain all instances of overshooting the target as these errors also occur in the serial condition.
Chapter 3: Study Two
Age effects on the interpretation of coordinate dimensions.

Introduction

Developmental differences in performance

The results of Study One suggest that developmental differences exist in children’s ability to accurately construct coordinates to locate a point in two-dimensional space. Older children scored a greater number of correct responses than younger children and showed increased accuracy with age as indicated by a greater number or responses coded as correct according to the Absolute Accuracy criterion. These findings are supported by those of Lidster (2000) who compared performance between nursery (three to four year old) and reception (four to five year old) children on construction and interpretation tasks and found older children’s performance superior to that of younger children.

Age related differences in performance have been detected in a variety of tasks. Bryant and Somerville (1986) detected age differences between six and nine year-old children in the ability to extrapolate from one line to another when given a function line. Performance by nine year olds was superior to that of six year olds who were significantly less accurate than the nine year olds. Somerville & Bryant (1985, Experiment One) report a significant main effect of age amongst five to seven year olds on two different interpretation tasks. In one task (the sticks task) children were asked to indicate which of four counters on a board indicated where two obliquely placed sticks met. On the other task children had to indicate at which of four blocks two Lego men would meet if they walked in a straight line. Older children performed significantly better than younger children. Similar results were reported on a pencil and paper task (Experiment Two).

Blades & Spencer (1989) looked at the ability of four to six year old children to construct and interpret coordinate references using a grid of sunken squares and found a significant effect of age on children’s ability to interpret both alpha-numerical and colour coded coordinate references with performance by six year olds being superior to that of four year olds.
The advantage of construction tasks over interpretation tasks.

As previously mentioned, the results of studies that aim to look at both the construction and interpretation of coordinate dimensions have improved ambiguous. Whereas Lidster and Bremner (1999) report that overall performance on construction tasks is superior to that on interpretation tasks, this superiority was absent in the findings of Blades and Spencer (1989). One possible explanation for this may be methodological differences. As stated earlier Lidster & Bremner (1999) used a large board with orthogonally placed markers which pointed to one of four target cups whereas Blades & Spencer (1989) used a grid of nine sunken squares and required the identification of the correct colour coded grid reference card. As the greatest differences in performance between construction and interpretation tasks occur in the Far-Far trials in Lidster & Bremner’s study, it may be that problems encountered during these trials are distorting the results. Similarly the order effects found in Lidster & Bremner’s study relate predominantly to improvements in performance on the Far-Far interpretation task when preceded by a construction task. These results suggest that the effects found in Lidster & Bremner’s studies lie in children’s inability primarily to solve Far-Far problems in their interpretation task and that this is improved through exposure to the construction task.

In addition to finding an advantage of construction tasks over interpretation tasks Lidster & Bremner (1999) report an overall effect due to trial type in both construction and interpretation tasks. Study One also found also found differences due to trial type but in addition found that performance on Far-Far trials was facilitated by simultaneous responding. Somerville & Bryant (1986) report a significant effect of distance over which children had to extrapolate a line and that this interacted with age. In their study nine year olds showed no difference in accuracy due to distance but six year olds showed greater errors for longer extrapolations.

The effect of scoring criteria

The results from Study One suggest that assessment of the level of performance on spatial tasks is significantly affected by the accuracy of the measurement used and that this has a differential effect between older and younger children. This study aims to investigate levels of performance on interpretation tasks when a more stringent standard of measurement is applied.
Aims of this study

The aims of this study were to confirm Lidster & Bremner's (1999) findings with respect to trial type effects and also to determine whether the age effects present in the construction task in study 1 would also be present in an interpretation task. In addition to this a comparison between results from Study One and this study was planned in order to investigate the suggested advantage of construction over interpretation tasks which was present in Lidster & Bremner's (1999) study but not in Blades & Spencer's (1989) task. Of particular interest is the effect that age and method of scoring has upon the results and this study aims to discover whether accuracy in the interpretation of coordinate dimensions improves with age and how performance on interpretation tasks compares with that on construction tasks once more stringent criteria are imposed.

Method

Participants

Forty-two children between three years eleven months and five years nine months participated in this study (mean age four years eleven months). There were twenty-eight males and twenty-four females. The children were taken from a local nursery school and the reception year and year one of a local primary school. The school was in a predominantly white, middle-class area of Surrey. As the study was to be carried out in the classroom permission was sought from both parents and teachers (see Appendix 1). The children were further divided into two age groups on the basis of whether they were above or below the mean age of four years eleven months (mean age 4 years 6 months, n=21, range = 3 years 11 months- 4 years 11 months for the younger group and mean age 5 years 5 months, n=21, range = 5 years- 5 years 9 months for the older age group). None of the children had participated in Study One.

Materials

As in Study One, four identical Styrofoam cups, 3cm in height and 5cm in diameter served as hiding locations. These were placed with their centres approximately 25cm apart on the apparatus as used in Study One and a card teddy measuring approximately 4cm in height was used as a hiding object. The apparatus was placed on the floor to enable the child to look down on it.
Design

Experiment Two consisted of an interpretation task. A multivariate design was used to gauge the effects of more than one independent variable simultaneously. The between-participant variable was Age, which comprised of two levels, above and below the mean age of four years eleven months. The within-participants variable manipulated was Trial Type. As in Experiment One there were four levels of Trial Type, Near-Near, Near-Far, Far-Near and Far-Far. Children were given an interpretation task equivalent to that of Lidster & Bremner (1999) where they were presented with trials in which a small cardboard teddy was hidden beneath one of four cups and the children had to state which of the four cups the teddy was hiding under. The location of the teddy was cued using two orthogonally placed pointers and the position of the target and the axes was manipulated by rotating the board giving rise to four trials in each of the four different positions, each corresponding to a different trial type. The dependent variable was the number of times the children correctly identified the target cup in which the teddy was hidden over the course of 16 trials.

Procedure

Each child was tested individually in a quiet corner of the classroom by the author. Before the task it was explained to them that they were going to play a game called ‘find the teddy’. The experimenter explained that she was going to hide the teddy under one of the upturned cups and that she would move the pointers so that they both pointed to where teddy was hiding. During the explanation the experimenter hid teddy as for a Far-Far trial, lined up the pointers correctly, traced imaginary lines with her finger and explained that the imaginary lines would meet where teddy was hiding. (‘See, if you draw a straight line out from the pointers, where they bump into each other, that’s where teddy is hiding….look there he is!). At this point the cup was lifted to reveal teddy. The child was given two practice trials.

The introduction was followed by sixteen trials. These trials represented all possible combinations of the four different positions of the hiding place and the four different trial types as in Study One. The trials were presented in a randomised sequence. The child was instructed to ‘close your eyes and turn around while I hide teddy’ and the experimenter hid the teddy under one of the cups. The experimenter then moved the pointers to indicate the teddy’s location and asked the child ‘can you show me where teddy is hiding’ When the child had pointed to a cup the experimenter
picked up the cup indicated by the child with the words ‘is he there’ and if so replied ‘yes’. If the teddy was not there he was then retrieved from under the correct cup with the words ‘there he is’. This procedure was repeated for all sixteen trials.

**Results**

In the interpretation task the child was presented with one cup in each quadrant of the board and was required to select the correct cup to which the markers were pointing. As the child had only the choice of selecting the correct cup or an incorrect cup which lay outside the correct quadrant there was no possibility of selecting an incorrect location within the correct quadrant. Therefore, in contrast to Study One, responses in the interpretation task could only be recorded as correct or incorrect.

Table 3.1 shows the mean number of correct responses for each trial type. Using the same criteria as in Study One, the children’s total number of correct responses was compared to a binomial probability of .50 of correctly responding. The number of children responding at a level above chance (12 out of 16, p<0.05) was calculated as 50.1%.

**Table 3.1:** Mean number of correct responses out of 4 (S.D. in brackets) for each trial type.

<table>
<thead>
<tr>
<th>Trial Type</th>
<th>Near-Near</th>
<th>Near-Far</th>
<th>Far-Near</th>
<th>Far-Far</th>
<th>Total (/16)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.36(.88)</td>
<td>2.88(1.11)</td>
<td>3.00(1.12)</td>
<td>2.14(1.50)</td>
<td>11.33(3.87)</td>
</tr>
</tbody>
</table>

Preliminary screening of the data revealed no significant sex differences in mean scores on any of the trial types and so data analysis did not include gender. Data were analysed by means of a two-factor Trial Type x Age ANOVA with repeated measures on the first factor and analysis of the data revealed a significant main effect of Age (F (1, 40) = 21.06, p<0.001) with older children scoring significantly more correct responses than younger children. There was also a significant main effect of Trial Type (F (3,120) = 20.48, p<0.001) with performance on Near-Near trials being superior and performance on Far-Far trials being the poorest. In addition there was a significant Age x Trial Type interaction (F (3,120) = 2.93, p<0.05) (see Figure 3.1). Younger children performed much more poorly on the Far-Far trials in comparison to other trial types and
the difference between older children’s and younger children’s performance was greatest in Far-Far trials.

Figure 3.1. Mean number of correct responses (out of 4) by trial type and age group

<table>
<thead>
<tr>
<th>Trial type</th>
<th>&lt; 4 years 11 months (n=21)</th>
<th>&gt; 4 years 11 months (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>near-near</td>
<td></td>
<td></td>
</tr>
<tr>
<td>near-far</td>
<td></td>
<td></td>
</tr>
<tr>
<td>far-near</td>
<td></td>
<td></td>
</tr>
<tr>
<td>far-far</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Error Analysis

Analysis of the types of errors made on the interpretation task was considered important as a source of insight into children’s strategies when completing the task. The responses were encoded in terms of their location in relation to the Near-Far and left-right markers. Of a total of 194 errors approximately 72% consisted of selecting a cup nearest to either the left/right or near/far marker and approximately 20% consisted of selecting a cup in line with one of the markers. Less than 8% of the wrong selections made involved choosing a cup that was not in line with either marker (See Figure 3.2). These results suggest that children are systematically choosing a cup nearest to one of the pointers and are not taking the position of the other marker into account or doing so incorrectly. Although younger children made the majority of errors the pattern of these errors did not differ greatly from that of the older children.
The aims of the study were to investigate whether the age effects present in young children’s performance on construction tasks were also present in interpretation tasks. At the same time the experiment sought to confirm the findings of Lidster & Bremner (1999) concerning the presence of trial type effects in interpretation tasks. The results of this study suggest that roughly half of the children between the ages of three years eleven months and five years nine months are able to interpret orthogonally placed cues to the location of objects. These findings are consistent with those of Lidster & Bremner (1999) who found that approximately 46% of their subjects scored twelve or more correct responses out of sixteen. As in Study One, the predicted age effect was again evident with younger children scoring significantly fewer correct responses than older children, especially in Far-Far trials. However due to the constraints of choosing from a limited number of fixed choices, accuracy could not be gauged. Analysis also showed an effect of trial type consistent with that found in Lidster & Bremner’s (1999) study, where performance on Near-Near trials was
superior and performance on Far-Far trials was inferior to other trial types, and in Study One.

**Comparison of studies 1 and 2**

Although Study One found no difference in performance between the serial and simultaneous condition, it was felt that a comparison of results from the interpretation trials in Study Two and the simultaneous construction condition in Study One would identify whether differences in performance between construction and interpretation tasks persisted if children were required to coordinate the spatial references simultaneously during both tasks. Results from this study were compared with those from the simultaneous condition of Study One. Data from the simultaneous condition of Study One (N=43, mean age four years ten months) was combined with the data from Study Two (see Table 3.2). The children were divided into two age groups on the basis of whether they were above or below the mean age in Study Two. Although the mean ages of the groups used in each study differed slightly, the distribution of the ages meant that this affected only one child with regard to whether they were allocated to the younger or the older age group.

**Table 3.2.** Mean scores per trial type out of four (s.d. in brackets) for interpretation task (Study Two) and simultaneous construction task (Study One) showing construction task scores according to both Correct Quadrant (CQ) and Absolute Accuracy (AA) criteria.

<table>
<thead>
<tr>
<th>Trial type</th>
<th>Near-Near</th>
<th>Near-Far</th>
<th>Far-Near</th>
<th>Far-Far</th>
<th>Total (/16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpretation</td>
<td>3.36(0.88)</td>
<td>2.88(1.11)</td>
<td>3.00(1.12)</td>
<td>2.14(1.50)</td>
<td>11.33(3.87)</td>
</tr>
<tr>
<td>Construction (CQ)</td>
<td>3.42(1.12)</td>
<td>2.74(1.27)</td>
<td>3.37(1.02)</td>
<td>3.56(0.63)</td>
<td>13.07(3.31)</td>
</tr>
<tr>
<td>Construction (AA)</td>
<td>3.12(1.26)</td>
<td>2.21(1.58)</td>
<td>2.67(1.43)</td>
<td>2.21(1.63)</td>
<td>10.19(5.03)</td>
</tr>
</tbody>
</table>

Two three-factor Trial Type x Age x Task ANOVAs were carried out with repeated measures on the first factor. The first of these compared the results of the Interpretation Task with those of the Construction Task using the Absolute Accuracy Criterion, whereas the second compared the results from the Interpretation Task with those of the Construction Task using the Correct Quadrant criterion.
Using the Correct Quadrant criterion, significant main effects were found for Trial Type ($F(3,243) = 12.67, p<0.001$), with performance on Near–Near trials superior to that on other trial types; Age ($F(1,81) = 16.39, p<0.001$), where older children scored significantly better than younger ones; and Task ($F(3,243) = 7.94, p<0.01$), performance on the construction task being superior to that on interpretation. There was also a significant Trial Type x Task interaction ($F(3,243) = 20.34, p<0.001$) with greatest differences in performance between the tasks being noticeable on Far-Far trials, and a significant Trial Type x Task x Age interaction ($F(3,243) = 2.89, p<0.05$). Older children showed superior performance than younger children in all trial types in the construction task except Far-Far trials, which showed no improvement with age.

Using the Absolute Accuracy criterion, significant main effects were again found for Trial Type ($F(3,243) = 27.7, p<0.001$). The greatest number of correct responses was for Near-Near trials and the least for Far-Far trials. A significant main effect of Age ($F(1,81) = 21.50, p<0.001$) was present and yet again older children performed more accurately than younger ones, but no main effect was apparent for Task ($F(3,243) = 1.19, p=0.28$). A significant Trial Type x Age interaction was again apparent ($F(3,243) = 3.93, p<0.05$). Younger children performed significantly more poorly in the Far-Far trials in comparison to other trials and the difference between younger and older children’s performance was greatest in Far-Far trials. In addition a Trial Type x Task interaction ($F(3,243) = 3.23, p<0.05$) was present. Performance in the Interpretation task was superior to the Construction task in all trial types except Far-Far trials.

**Discussion**

Comparison of the results from Studies One and Two suggest that the predicted age effect is present in both interpretation and construction tasks. This is consistent with the findings of Lidster (2000) who also found a significant age effect to be present on construction and interpretation tasks suggesting developmental differences in ability to interpret and construct orthogonal cues to location. Of note is the difference in results emerging through the use of differing scoring criteria to assess performance on the construction task. Differences in performance between construction and interpretation tasks were found when using the correct quadrant criterion but not when using the Absolute Accuracy criterion. This leads to the
question of to what degree are we truly able to gauge the child’s ability to interpret coordinate dimensions in a task where they are required to select an object from a very limited number of distinctly located objects. In the construction condition the child is able to use the materials to point to any location on the board and yet the child’s ability to correctly locate a point shows lower levels of success than previously estimated using Lidster and Bremner’s criteria. By presenting the child with more possible choices in the interpretation task we can ascertain the degree to which children can accurately interpret cue to location and the effects of measurement constraints upon performance. In addition sources of bias in responding can also be investigated.
Chapter 4: Study Three

The effect of two-dimensional and three-dimensional materials on performance in a spatial interpretation task

Introduction

Results from Studies One and Two support the idea that there are developmental differences in children's ability to construct and interpret orthogonal cues to location. Study One demonstrates that in construction tasks, there are age-related differences both in the amount of correct responses the child gives and in the accuracy of those responses in terms of fine-grained ability to locate a point in space. Study Two demonstrates that the ability to interpret coordinate dimensions does also improve with age. However one problem arising from the comparison of Studies One and Two is that of measurement accuracy. It has been observed that when comparing the children's ability to interpret coordinates (as measured by their ability to select the correct cup out of a possible choice of four) to their ability to construct coordinates (by asking them to place pointers so that they point to one of these four cups) we get markedly different results depending on the classification of a correct response. If we require a correct response on construction tasks to point to a location within the area of the cup, then we find that there is no main effect due to the type of task; thus the proposed superiority in construction tasks proposed by Lidster & Bremner (1999) is not evident.

However if the requirement is simply to point to a point nearer to the target cup than to any of the other cups then Lidster & Bremner's findings are supported. This raises the issue of developing comparable tasks for both interpretation and construction conditions which will allow us to gauge and compare children's accuracy on both tasks. In the construction task the child is able to use the materials to point to any location within the confines of the board whereas in the interpretation condition the child's responses are tightly constrained by the limited number of possible choices. One aim of this study is to present the child with an interpretation task with a greater number of possible choices to ascertain to what degree of accuracy children
can interpret cues to location so that a direct comparison can be drawn with the results of Study One especially in terms of increased accuracy with age.

In addition this study aims to investigate sources of error in children’s responses. It was noted in Study Two that children’s errors frequently consisted of choosing the cup nearest to one of the markers (72%) or in line with one of the markers (20%). Similarly Bremner, Andreasen, Kendall & Adams (1993) found that a search near to one or other of the location cues to be more frequent than other error types. However with the choice of locations limited to four it is difficult to interpret these findings. In this study selection of a cup nearest to either marker guarantees success in Near-Near trials, gives a 50% chance of success in Near-Far and Far-Near trials and ensures failure in Far-Far trials. This may in part explain the superiority on Near-Near trials and inferiority on Far-Far trials found in previous studies. Bremner et al. (1993) found that under the basic condition in their study there was ‘little evidence that children could solve problems other than the Near-Near one’ and suggest that the actual scores in the basic condition are close enough to suggest this is the dominant strategy. They suggest that this is abandoned as a heuristic when it does not lead to success and that in such circumstances search on Far-Far trials becomes more random. However subsequent studies have reported higher rates of success to suggest that this is not the sole strategy employed. Blades & Spencer (1989) found that a significant percentage of incorrect choices in their interpretation tasks lay under one or other of the given coordinates but that there was no significant tendency to select a location adjacent to one of the markers except amongst the four year olds in Experiment One. The experiment reported in this chapter aims to investigate this further by examining errors made in a revised interpretation task and developmental differences in those errors.

The effect of context on task performance

In studies investigating children’s ability to interpret coordinate dimensions, considerable effects have been found due to the type of task involved. Somerville & Bryant (1985) looked at children’s ability to interpret spatial coordinates using two techniques. One involved slides of two-dimensional materials, whereby children had to state at which of four counters two obliquely placed rods would meet. The other involved slides of three-dimensional materials and children had to state at which of four blocks, two Lego men would meet if they walked in a straight line. They found
that children performed significantly better under the people task suggesting that children are more able to complete these tasks when more meaningful, line-of-walk materials are used. Bremner, Andreasen, Kendall & Adams (1993) gave children between three years eight months and five years three months a series of interpretation tasks where the child had to located an object hidden under one of four upturned cups. In Experiment One the locations were indicated either by coloured dots or by toy people on the orthogonal edges of a board. They found performance on the line-of-walk (people) task significantly better than on the basic task and performance on Near-Near trials superior to that on Far-Far trials. However performance on Bremner et al.'s (1993) three-dimensional version of the people task yielded results which were no better than those found in Somerville & Bryant's experiment and, in the case of Far-Far trials may have been significantly worse. The findings of these experiments suggest that the 'dimensionality' of the task with regard to the materials used and the 'human sense' of the task may have differing effects upon the results.

It has been argued that the familiarity of materials used in tasks with children may affect performance (McHale & West; 1980). Lidster (2002) suggests that as three-dimensional arrays are more commonly encountered in everyday life then a three-dimensional task might be seen by children as more 'concrete and tangible' and so higher in 'human sense' and lead to superior performance. However, in contrast to this expectation her results showed poorer performance in the three-dimensional task than the two-dimensional task. In this study we present the task in the form of pictures (2-D) of animals from a 'picture lotto' game and toy animals (3-D) which, if not specifically encountered before by the children will, it is hoped, provide a familiar context in which to participate.

Two-dimensional versus Three-dimensional tasks

The results of previous studies such as Bremner et al. (1993) suggest that young children perform coordinate interpretation tasks more effectively when these tasks are embedded within a meaningful line-of-sight setting. It is suggested that the child's understanding of the linearity of lines of sight in addition to the aspect of 'human sense' lead to improved performance under these conditions. However the concept of human sense requires clarification. Hughes & Donaldson (1979) suggest that in their study children's performance was aided by an understanding of the
motives and intentions of characters within the task. Both the line-of-sight and the line-of-walk conditions in Bremner et al.’s (1993) study would seem equivalent in these terms. One problem, however, with interpreting superior performance on the line-of-sight task arises due to the materials used. By necessity the figures used in the line-of-sight task had to protrude above the height of the hiding locations to afford a ‘view’ whereas in both the line-of-walk and the arrow conditions the figures cues to location were of equal or lower height to the upturned cups. The relationship between the heights of the markers and the hiding locations may have had some effect upon the results. The hiding locations may have had a ‘masking effect’ particularly in the case of Far-Far trials when the target object is ‘hidden’ behind a non-target object.

Lidster (2002) compared the performance of three-and-a-half to four-and-a-half year old children on three-dimensional and two-dimensional versions of Lidster & Bremner’s (1999) construction and interpretation tasks. Children were presented with either a task where toy dogs were hidden beneath one of four upturned cups, 5cm in diameter, or a task where laminated pictures of dogs were hidden beneath one of four laminated paper circles, 5cm in diameter. Lidster (2002) found evidence to support the suggestion that the presence of hiding locations between the pointers and the target location in the three-dimensional condition may have a ‘masking effect’. She found a significant main effect due to dimensionality with superior performance by the two-dimensional group and also a significant main effect of type. Analysis of the results suggests that an overall superiority in the two-dimensional condition is limited to the construction task. Of particular note, however, was an interaction between trial type and dimensionality whereby performance on Far-Far trials in both construction and interpretation tasks was significantly better in the two-dimensional condition compared to the three-dimensional condition. However the group in the two-dimensional condition was approximately six months older than that in the three-dimensional condition and so one aim of the present study is to compare performance of similarly aged children on two- and three-dimensional tasks and to look for age effects across these tasks.
Aims of this study

In summary, the aims of this study are three-fold. First, we aim to study children’s performance on an interpretation task that offers an increased number of possible choices with regard to a target location. In particular we wish to compare levels of accuracy with those achieved in a construction task and to look for the age related differences in accuracy which are evident in a construction task. A second aim is to look at sources of error in the interpretation task. Of particular interest is the aspect of near-marker selection as found in the studies of Bremner et al. (1993). The use of this ‘search-next-to-pointer’ strategy would lead to a lesser degree of success on all types of task in our study as no type of trial can be successfully solved using this method. Analysis of error types should determine to what degree this strategy is utilised as a heuristic as well as revealing any age related differences in error patterns. It is expected that older children may perhaps rely less on this type of strategy if, as Piaget suggests, they are less dependent on topological cues to location than younger children. Finally we aim to compare performance on three-dimensional and two-dimensional tasks between groups who are similarly aged and who have had equal amounts of school experience. The differences found in Lidster’s (2002) study may be age related and so developmental differences in performance will also be considered.

Method

Participants

Eighty-six children between three years ten months and five years ten months (mean age approximately five years) participated in this study, of whom fifty were male and thirty-six were female. The children were taken from the nursery, reception year and year one of a local primary school. The school was in a predominantly white, middle-class area of Surrey. As the study was to be carried out in the classroom permission was sought from both parents and teachers (see Appendix 1). The children were randomly assigned to one of two conditions such that the mean ages of the two groups were comparable. The children were further divided into two age groups on the basis of whether they were above or below five years old (Mean age for the younger group approximately 4 years and 6 months, n =39, range = 3 years 10 months- 4 years 11 ½ months. Mean age for the older group approximately 5 years 5 months, n=47, range = 5 years- 5 years 10 months). None of the children had participated in Studies One or Two.
Children were presented with an interpretation task in either a two-dimensional or three-dimensional form. The two-dimensional form consisted of a 50cm x 50 cm sheet of card mounted at one corner of a 60cm x 60cm MDF base with wooden pointers on a sliding mechanism along two sides. The cardboard was divided

Figure 4.1: Apparatus used in the two-dimensional condition

Figure 4.2: Apparatus used in the three-dimensional condition
into four quadrants each containing nine equally spaced pictures of farm animals (three by three array) — a total of thirty-six pictures in all (see Figure 4.1). The central picture in each quadrant corresponded to the position of the cup in Study One (target position). The sliding mechanisms were divided into six and marked in an unobtrusive way to aid classification of responses. In the three-dimensional task the children were presented with nine model farm animals in each quadrant (see Figure 4.2). In both conditions the apparatus was placed on the floor to enable children to look down on it.

**Design**

Experiment Three consisted of an interpretation task. A multivariate design was implemented to allow the effects of several independent variables to be assessed simultaneously. As in Experiment One, the design included within-participant variables of Pointer Position (four levels), Target Position (four levels) and Trial Type (four levels) and the between-participants independent variables of Age (two levels, above or below the age of five years old). In addition there was a further between-participants variable of Condition which related to whether the task was presented to the children using two-dimensional or three-dimensional materials. Each child was given either the three-dimensional (model animal) condition of the interpretation task or the two-dimensional (animal picture) condition of the interpretation task.

As in Studies One and Two the position of the target and the axes was manipulated by rotating the board, giving rise to four trials in each of the four different target positions, each corresponding to a different trial type — a total of sixteen trials in all. The dependent variable was the number of correct responses given by the children according to the two criteria outlined in Study One. If the children indicated the animal at the intersection of the two imaginary lines drawn from the pointers their response was classified as correct according to the Absolute Accuracy criterion. If they indicated an animal within the same quadrant they were classified as correct according to the Correct Quadrant criterion.

**Procedure**

The procedure was essentially the same as that in Study Two. Each child was individually tested in a quiet corner of the classroom. Before the task it was explained that they were going to play a game. The experimenter explained that she was going...
to point to one of the animals on the board with the two pointers and that the child had
to tell the experimenter by pointing with their finger, which animal the experimenter
was pointing to. During the explanation the experimenter used the same technique as
in Studies One and Two to illustrate the requirements of the task. The experimenter
placed the pointers so that they were pointing to one of the animals on the board and
traced imaginary lines with her fingers to the animal indicated, explaining that 'if you
were to draw a straight line out from this pointer and a straight line out from this
pointer, where the lines meet is the animal I am pointing to. Both pointers are pointing
to it at the same time'. The child was then given an opportunity for two practice trials,
one at a Far-Far location and one at a Near-Near location. The children were then
presented with sixteen trials corresponding to the same combinations of trial type
(Near-Near, Near-Far, Far-Near and Far-Far) and position on the board (Near left, Far
left, Near right and Far right) as in Studies One and Two. The trials were presented in
random order. As in Studies One and Two the experimenter pointed to the central area
of one of the quadrants using the two orthogonally placed pointers according to the
trial number and the child was requested to point with their finger to show which
animal the experimenter was pointing to. If the child correctly identified the animal
that the pointers indicated, the experimenter replied with the phrase 'yes, that's right'
if the child was incorrect they were told which animal the experimenter had been
pointing to.

Results

Results were recorded by marking the location of the animal the child had
pointed to on a six x six grid visible only to the experimenter. Table 4.1 shows the
number of correct responses by trial type using both the criteria used in Study One.
Based on the probability of 0.167 responding correctly by attending to only one
marker (one in six), the children's total correct responses were compared to a
binomial distribution. It was found that approximately 70% of children scored 6 or
more correct answers (binomial probability<0.05).

Preliminary screening of the data revealed no significant sex differences in
mean scores on any of the trial types and so data analysis did not include gender. As
we wished to establish how responses in this study compared with responses in the
construction condition, data were again analysed using two separate scoring criteria,
one assessing the children’s ability to correctly pinpoint an exact location and the
other to assess the ability to identify a more general area in which the target was located.

Two four-factor Position (4) x Pointer (4) x Age (2) x Condition (2) ANOVAs were carried out, one for each scoring criteria, with repeated measures on the first two factors. Both criteria revealed a significant main effect for Age (F (1, 82) = 17.27, p<0.001, for Absolute Accuracy, F (1, 81) = 16.33, p<0.001 for Correct Quadrant) with older children, as previously, performing significantly better than younger ones, (see Figure 4.4).

The Correct Quadrant criterion also revealed a significant main effect of Position (F (3, 243) = 3.05, p<0.05). Performance on far/left trials was superior to that on all other types. No main effect for condition was evident for either condition, F (181) = 0.55, p=0.45 for the Absolute Accuracy criterion and F (1, 81) = 0.25, p=0.62 for the Correct Quadrant criterion. Both the Correct Quadrant and Absolute Accuracy Criteria revealed a significant Position x Pointer interaction (F (9, 729) = 7.32, p<0.001 and F (9, 729) = 8.64, p<0.001 respectively). As in Study One it was felt that this pointer x position interaction could be explained as an effect of trial type and consequently two 3-factor Trial Type (4) x Condition (2) x Age (2) ANOVAs were carried out, one for each of the scoring criteria, with repeated measures on the first factor. These revealed a significant main effect of Trial Type (F (3, 82) = 22.54, p<0.001).
p<0.001 for Absolute Accuracy and F (3, 82) =15.70, p<0.001 for Correct Quadrant) in addition to the Age effects found in the earlier analysis. The effect of Trial Type was such that performance on the Near-Near trials was superior to that on all other trial types and performance on Far-Far trials was poorer than that on all other trial types (see Figures 4.3a and 4.3b). Comparisons were made between scores according to the two criteria. As in Study One, scores according to the Correct Quadrant criterion were significantly higher than those according to the Absolute accuracy criterion (t=11.35, p<0.001, 85 d.f., one-tailed). In addition younger children showed greater differences in scores according to the two systems than older children, suggesting that accuracy improves with age (t=3.05, p<0.005, 84 d.f, one-tailed) (see Figure 4.4).

Figure 4.3a: Mean scores (out of four) by trial type, under Correct Quadrant (CQ) scoring criteria

![Bar chart showing mean scores by trial type](image-url)
Figure 4.3b Mean scores (out of four) by trial type, under Absolute Accuracy (AA) scoring criteria

Figure 4.4 Mean number of correct responses (out of sixteen by age group) using Correct Quadrant and Absolute Accuracy scoring criteria
Error Analysis

Errors were coded into three categories. The first category was selection of a location next to one of the pointers, category two was selection of a location in line with only one of the pointers and the third category was selection of a location which was not in line with either pointer. Of the total number of errors (N=567) 83% consisted of selection of a location in line with one or other of the pointers, including 20% (n=112) of errors which involved selection of a location next to one of the markers. Seventeen percent of the total errors involved the selection of a location not in line with either marker. Figure 4.5 shows the distribution of errors by trial type. A comparison of the errors made by younger and older children showed that

Figure 4.5 Frequency of different error types by trial type (N=567)
**Figure 4.6a:** Frequency of three error types by condition amongst children **younger** than five years old.

![Bar graph showing error type frequency by condition for younger children.](image)

**Figure 4.6b:** Frequency of three error types by condition amongst children **older** than five years old.

![Bar graph showing error type frequency by condition for older children.](image)
approximately 26% of the younger children’s errors consisted of choosing a location next to one of the pointers and that there was little difference in this between conditions. In contrast only approximately 9% of older children’s errors were of this type. Although younger children show a similar number of each error type between conditions, older children show more variation between conditions. In particular, older children show a significantly greater number of errors which are not in line with either pointer on the three-dimensional condition than they do on the two-dimensional condition. ($t=2.10$, $p<0.005$, two-tailed, 45 d.f). The number of these types of errors produced by older children is similar to that of the younger children in the three-dimensional condition but decreases considerably in the two-dimensional condition (see Figures 4.6a and 4.6b).

**Summary of findings**

Approximately 70% of children were performing at levels above chance. Significant main effects of Trial Type were found with performance on Near-Near trials being superior and performance on Far-Far trials being inferior in both two-dimensional and three-dimensional conditions. Age related effects were also observed; the performance of older children showed a greater number of correct responses and accuracy also improved with age as indicated by a greater difference between scores according to Correct Quadrant and Absolute Accuracy amongst the younger age group. No effect of condition was found; children performed equally well on two-dimensional and three-dimensional interpretation tasks. Finally, in terms of error, approximately 83% of errors consisted of choosing a location in line with one or other of the markers.

**Discussion**

The results of Study Three found no overall difference between performance on two-dimensional and three-dimensional interpretation tasks. This suggests that the superiority in performance on line-of-sight tasks found by Bremner et al. (1993) is not merely due to the simple factor of the marker protruding above the height of the cups, leading to easier extrapolation of the lines, as this would lead to superior performance in the two-dimensional task in this study. This was not the case. However the main improvement between line-of-sight and line-of-walk conditions in
their study seems to consist of an improvement in Far-Far trials. One possible explanation for the difference between performance on the line-of-sight and line-of-walk condition may be that the instructions given to the child made the objectives clearer. In Bremner et al.'s study children were expressly told that although 'in every case each person could be looking at two cups, there was only one cup that they were both looking at' (Page 160). It is not clear whether an explicit statement of this nature was made in the other tasks. The results from the basic and arrow interpretation tasks in Bremner et al.'s study appear show poorer levels of performance than those found in Study Two with the exception of Near-Near trials. During the introduction to our task, it was stressed that both the arrows were pointing to the target at the same time. This may go some way to explain the different levels of performance.

The lack of any difference in levels of performance between the two-dimensional and the three-dimensional task suggests that the familiarity of three-dimensional arrays compared to two-dimensional arrays does not affect performance. This is also supported by Lidster (2002) who found, in contrast to expectations, that performance on her two-dimensional task was superior to that on the three-dimensional task. Lidster (2002) found that performance on Far-Far trials was better in the two-dimensional condition compared to the three-dimensional condition. We found partial support for these findings. Although there was no effect on numbers of correct responses between the two- and three-dimensional conditions, there were significantly more errors not in line with either pointer in the three-dimensional condition amongst the older children and the majority of these errors were made in the Far-Far condition. The children in Lidster's two-dimensional task were approximately six months older than those in the children in the three-dimensional task and it may be that her analysis, using the four-cup task, has picked up this difference in error types between the conditions in older children and given it more salience than it would have achieved had children of more similar ages been compared.

The error types observed in the present study suggest that although 'search-next-to-pointer' may be one method used to identify the target location it is by no means the dominant one. Bremner et al. (1993) suggest that this strategy is a heuristic which is abandoned when it never leads to success and that abandonment of it as a strategy leads to more random search or selection. The present study involved a task encompassing all trial types whereby the 'search-next-to-pointer' heuristic would never lead to success in any trial type. Error analysis shows that, as Bremner et al.
(1993) propose, in such a situation 'next-to-pointer' selection occurs in relatively few cases. Search errors appear more systematic than those displayed in Bremner et al.’s (1993) study, the majority of errors were in line with one or other of the pointers, even in the Far-Far trials. These findings are consistent with those of Blades & Spencer (1989) who suggest that although the majority of errors are in line with one or other of the pointers, there is no significant tendency to select a location adjacent to the marker except amongst four year olds. The present study found that these errors formed a greater percentage of the total errors made by the younger age group than they did the older age group.

The differences in the findings of the current study and those of Blades & Spencer (1986) and Bremner et al.’s (1993) study may be related to the number of possible response choices. The current study presented children with a six by six array and Blades & Spencer presented children with a four by four array. Bremner et al.’s study provided a two by two array with a choice of only four possible target locations and this may have affected the results. The value of the ‘search-next-to-pointer’ strategy as a heuristic in the two by two array used by Bremner et al. (1993) is far greater than in larger arrays. In the case of a two by two array, such a strategy would lead to success in all Near-Near trials, in half of the Near-Far and Far-Near trials and only be completely inappropriate in Far-Far trials. In the four by four array used by Blades & Spencer (1989) the use of ‘search-next-to-pointer’ gives a 25% probability of being correct since all of the 16 squares on the board were used as target locations, whereas in this study selection of a location next to the pointer has no value as a heuristic since the target location is never one of those next to the pointer and so this strategy has a 0% probability of success. A comparison of performance and errors made in the interpretation condition of the standard four-cup task and this task, which involves choosing from a greater number of possible locations, may clarify whether the use of this strategy is related to its value as a heuristic.

**Comparison between performance on standard three-dimensional interpretation task and Study Three**

The results of the present study reinforce those of Studies One and Two which found significant age and type effects. However methodological differences between Study Two, using the four-cup design, and Study Three may have given rise to
differences in performance on these interpretation tasks. In order to establish what effects the changes in methodology and materials may have had on the results a comparison between the results of Study Two and Study Three was carried out. Despite the lack of an effect of dimensionality in the results of the present study it was felt that a direct comparison between the data sets from the three-dimensional condition of this study (model condition) and the data set from Study Two (four-cup condition) was most appropriate as both studies involved a three-dimensional interpretation task. Table 4.2 shows the mean scores obtained in these data sets.

In the standard four-cup task approximately 50% of children between the ages of three years eleven months and five years nine months scored significantly above chance level, in comparison to 70% scoring above chance level in the Models task. Both data sets showed a significant effect of Age and Trial Type. Data from the two data sets was combined. As the mean ages for the two groups differed very slightly, the children were divided into two age groups on the basis of whether they were above or below the mean age for the combined group of 4 years 11½ months. (Mean age for the older group = five years four and a half months; mean age for the younger group = four years six months.)

Table 4.2: Mean scores (out of four) for each trial type (s.d. in brackets) according to data set (study)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Near-Near</th>
<th>Near-Far</th>
<th>Far-Near</th>
<th>Far-Far</th>
<th>Total (/16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Models</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQ</td>
<td>3.58(0.93)</td>
<td>2.98(1.08)</td>
<td>3.07(0.96)</td>
<td>2.37(1.56)</td>
<td>11.98(3.64)</td>
</tr>
<tr>
<td>AA</td>
<td>2.67(1.54)</td>
<td>2.28(1.52)</td>
<td>2.14(1.47)</td>
<td>1.63(1.50)</td>
<td>8.79(5.30)</td>
</tr>
<tr>
<td>Four Cups</td>
<td>3.36(0.88)</td>
<td>2.88(1.11)</td>
<td>3.00(1.12)</td>
<td>2.14(1.50)</td>
<td>11.33(3.87)</td>
</tr>
</tbody>
</table>

As performance in the basic (four cup) condition could only be assessed in terms of selecting the correct cup, comparisons were made between scores according to this criterion for the two conditions. A Trial Type (4) x Age (2) x Condition (2) ANOVA was carried out with repeated measures on the first factor. As might be expected from the separate analyses of each study, significant main effects for Trial Type (F3, 243) =31.98, p<0.001) and Age (F (1, 81) =18.38, p<0.001) were found.
Performance was again superior in Near-Near trials and inferior in Far-Far trials with intermediate levels of performance in Near-Far and Far-Near trials. Younger children scored significantly fewer correct responses than older children.

In addition a main effect of Condition was found ($F(1,81) = 8.95, p<0.005$). Children scored a greater number of correct responses in the basic (four cup) condition compared to the model condition. There was no evidence of any interactions between these variables.

**Discussion**

A comparison of error types between the two conditions suggests that the model condition, with its greater number of possible location choices, lead to a greater percentage of errors involving pointing to a location that was not in line with either pointer. The basic condition lead to less than 8% of errors of this type, however the model condition produced more than 17% of errors of this type. Also of interest is the proportion of errors that were classified as selection of a location next to the pointer. Whereas these constituted approximately 72% of errors in the basic task, only 20% of errors in the Model task could be so classified. Results suggest that in a four-cup task the prevalence of ‘next-to-pointer’ errors is far greater than found in this study and more in line with the findings of Bremner et al. (1993). This supports the suggestion that the use of this strategy is a reflection of the relative success of ‘next-to-pointer’ selection as a heuristic in the differing tasks.

**Comparison between the three-dimensional construction task and the three-dimensional interpretation task**

As the construction task presented in Study One was in a three-dimensional form, it was felt that a direct comparison between it and the three-dimensional condition of Study Three was most appropriate. As interpretation tasks require the consideration of two coordinates simultaneously, comparisons were made with the simultaneous condition of the construction task only. Table 4.3 shows the scores obtained for the construction and interpretation tasks using both scoring criteria.

The data were analysed by means of two three-factor Trial Type x Age x Condition ANOVAs, one for each of the scoring criteria, with repeated measures on the first factor. Separate analysis of both of the data sets from which these data were drawn had revealed significant effects for Age and Trial Type as outlined previously.
This pattern of effects was yet again in evidence with a main effect of Trial Type present according to both criteria \( F(3,246) = 20.54, p < 0.001 \) for Absolute Accuracy and \( F(3,246) = 12.24, p < 0.001 \) for Correct Quadrant. A main effect of Age was also present using both criteria. \( F(1, 82) = 16.10, p < 0.001 \) for Absolute Accuracy and \( F(1, 82) = 9.81, p < 0.005 \) for Correct Quadrant. No main effect of Condition was found according to either criterion. However, significant Trial Type x Condition effects were found for both Absolute Accuracy and Correct Quadrant criteria. \( F(3,246) = 2.93, p < 0.05 \) and \( F(3,246) = 15.76, p < 0.001 \) respectively. This interaction shows performance on Far-Far trials to be significantly poorer in the interpretation task than the construction task.

**Table 4.3.** Mean scores out of four (s.d. in brackets) for each trial type on construction and interpretation tasks according to Correct Quadrant (CQ) and Absolute Accuracy (AA) criteria.

<table>
<thead>
<tr>
<th>Trial type</th>
<th>Construction</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Near-Near</td>
<td>Near-Far</td>
</tr>
<tr>
<td>Simultaneous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQ</td>
<td>3.42(1.12)</td>
<td>2.47(1.27)</td>
</tr>
<tr>
<td>AA</td>
<td>3.12(1.26)</td>
<td>2.21(1.58)</td>
</tr>
<tr>
<td>Serial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQ</td>
<td>3.68(0.79)</td>
<td>3.32(1.06)</td>
</tr>
<tr>
<td>AA</td>
<td>3.20(1.75)</td>
<td>2.54(1.63)</td>
</tr>
<tr>
<td>Interpretation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQ</td>
<td>3.58(0.93)</td>
<td>2.98(1.08)</td>
</tr>
<tr>
<td>AA</td>
<td>2.67(1.54)</td>
<td>2.28(1.52)</td>
</tr>
</tbody>
</table>

Although no effect of simultaneous versus serial responding was found in Study One, two further three-factor Trial Type x Condition x Age ANOVAs were carried out, this time between scores on the serial construction condition of Study One and the three-dimensional interpretation condition of Study Three in order to ascertain whether the differences in performance between construction and interpretation tasks found in previous studies might also be explained in terms of serial responding in the construction condition. In addition to the Age and Trial Type effects reported in all
previous analyses, an effect of Condition (F (1, 80) = 6.64, p < 0.05) and a Condition x Trial Type interaction (F (3, 240) = 3.81, p < 0.05) according to the Correct Quadrant criterion.

**Discussion**

Comparison of the results of this study with the results of Study One revealed no difference in overall levels of performance between construction tasks and interpretation tasks according to either scoring criteria when children are required to respond simultaneously on the construction task. Children showed similar levels of performance on construction and interpretation tasks when both are assessed using the same scoring criteria.

These results differ from those of Lidster & Bremner (1999) and Lidster (2000) who consistently found performance on construction tasks to be superior to that on interpretation tasks. They do however support the findings of Blades & Spencer (1989) who found no difference between performance on Construction and Interpretation tasks in their task involving a grid of sunken squares. Subsequent comparison of performance in the serial construction task and the interpretation task suggests that this may be due to the use of serial responding in Lidster & Bremner’s study. Blades & Spencer’s task required the selection of the correct colour-coded coordinates and so may include a greater requirement to simultaneously consider the two coordinates than Lidster & Bremner’s task which could be solved by lining up each marker in turn.

In Lidster & Bremner’s (1999) and Lidster’s (2002) studies the main difference between performance is in Far-Far trials. Performance in Far-Far trials was worse on the interpretation task than on the construction task. The results of this study support the presence of a trial type x task interaction. Children’s performance on Far-Far trials was indeed superior on the construction task in comparison to the interpretation task. This is present even when scores were compared using the absolute accuracy criterion, which suggests that this is not an artefact of the greater number of correct quadrant responses on Far-Far trials present in the simultaneous construction condition (Study One).

The comparison between Study Three and Study One showed no difference in performance between the Construction and Interpretation tasks using the scores for the simultaneous condition of the construction task according to either of the scoring criteria. However, a Task x Trial Type effect was present with performance on the
Far-Far trials significantly worse in the Interpretation condition than the Construction condition. In a comparison between the Interpretation Task and the serial condition of the Construction task, an effect of Task (Construction versus Interpretation) and a Task x Trial Type interaction were present according to the Correct Quadrant criterion. This result suggests that, to some degree the differences between performance on Interpretation and Construction tasks may be due to the ability to perform the Construction task in a serial fashion as suggested by Lidster & Bremner (1999) but is present only when performance is assessed in terms of ability to construct coordinates for the correct quadrant but not when responses are assessed in terms of absolute accuracy. As in the previous analyses Trial Type and Age effects were present in all analyses.

Summary

Results of all three studies support the presence of age effects and trial type effects. Older children’s performance appears more accurate than younger children’s. This has also been found in earlier studies of spatial tasks (Bryant & Somerville; 1986, Lidster; 2002) and supports the notion of developmental constraints upon division of space (Sandberg, Huttenlocher & Newcombe; 1996). The greater degree of accuracy displayed by older children suggests that although younger children may be able to correctly identify a fairly broad area of space indicate by a set of spatial coordinates, the ability to fine-tune location and further subdivide space may develop with increasing age. The results also confirm the existence of an effect due to trial type, performance on Near-Near trials being superior to other types of trial and performance on Far-Far trials being poorest. This is particularly true in interpretation tasks compared to construction tasks (Lidster & Bremner, 1999; Lidster, 2002). One possible explanation for poorer performance on Far-Far trials is that children have difficulty extrapolating lines over larger distances, another is that the presence of objects between the pointer and the target lead to errors. Study Three showed that older children’s errors on Far-Far trials were influenced by the dimensionality of the materials used suggesting that the presence of other objects between the pointers and the target location may be a factor. Although younger children’s errors did not differ between the two-dimensional and three-dimensional conditions, older children’s errors did. Older children made fewer errors not in line with either pointer in the two-dimensional condition, suggesting that, when there are objects occluding the target
location, accuracy may be affected. The aim of the next studies is to explore these possible explanations.
Chapter 5: Study Four

The effect of removal of distractor items on children's ability to perform construction and interpretation tasks involving spatial coordinates.

Introduction

The results of Studies One to Three and of previous studies suggest that there are consistent age effects and consistent trial type effects in performance on spatial coordinate tasks. In most cases performance on Near-Near trials is shown to be superior and performance on Far-Far trials inferior with intermediate levels of performance on Near-Far and Far-Near trials. One exception to this is in Study One whereby performance on Far-Far construction trials was facilitated by simultaneous responding in terms of indicating the correct quadrant of a board that an object lay within. This was felt to be at least partially due to temporal coupling in bi-manual tasks (Kelso, Southard & Goodman, 1979). The effect of trial type is consistent across these and other studies (Lidster & Bremner, 1999; Lidster, 2002) and is at its strongest on interpretation tasks. It would appear that differences in performance on Far-Far trials between construction and interpretation tasks are a major source of variance between performance on construction and interpretation tasks.

Poorer performance on Far-Far trials could be a result of objects other than the target between it and the markers. This could lead to difficulties in pointing towards the target in construction tasks. It was noted that in construction trials some children consistently placed the pointers in order to afford an uninterrupted line between the pointer and the target cup. Results of Study Three suggest that the presence of intervening objects may affect results in interpretation tasks. A strategy of selecting an object adjacent to one of the markers was in evident in a number of trials and older children's errors were affected by whether the intervening objects were two- or three-dimensional. Somerville & Bryant (1985) noted that in their second experiment the hardest problems in both the rectangular and oblique tasks were those that required extrapolation past the first point on at least one dimension. It is therefore possible that
in a situation where there were no intervening objects between the pointers and the target then performance on items placed at the Far-Far location might be equal to that on Near-Near trials. An alternative source of error on Far-Far trials might be a difficulty in extrapolating lines over greater distances. Bryant & Somerville (1986) suggest that children, especially younger children, do have difficulty in extrapolating lines over greater distances. The six year olds in their study showed significantly greater error scores when required to extrapolate lines over a distance of 90mm compared with 60mm although older children showed no difference. If this were the source of difficulty then we would expect difficulties to persist even in the absence of intervening objects.

**Perceptual Support**

Perceptual support in spatial tasks refers to the provision of visible cues to support the child’s understanding of the requirements of the task. In particular perceptual support may be used to stress or reinforce the Euclidean nature of the task. There is some suggestion that the amount of perceptual support provided may influence success on spatial coordinate tasks. Lidster (2002) presented construction and interpretation tasks to three and four year old children. Perceptual support was provided in the introductory phase by means of detachable rods which intersected at the target location. Lidster found that the provision of perceptual support significantly improved the level of success among children, both in the initial testing phase and at follow up three months after initial participation. Blades & Spencer (1989) however found no difference in performance on construction and interpretation tasks between conditions where perceptual support was provided in the form of grid lines, and those where they were not. It may be however that in their study the layout of squares and the presence of grid referents on all sides provided sufficient perceptual support for the children. Somerville & Bryant (1985) found a difference in performance on an interpretation task between conditions involving choosing between sixteen irregularly placed dots and sixteen dots placed in a regular grid-like pattern. However, even within the irregular task the task may have been made easier for the children because the points they had to choose from formed a straight line which may have aided extrapolation and stressed the Euclidean nature of the task. Of particular concern is the configuration of the dots in the ‘irregular’ task which lead to the target dot lying along the only two straight lines of dots in the array.
All the previously cited research seems to provide some degree of perceptual support. Bryant & Somerville (1986), for example, introduced their later pencil and paper task using a Lego board which itself has a regular, grid-like pattern on it and the ‘rectangular’ display of the cups in the studies of Bremner et al. (1994), Lidster & Bremner (1999) and Lidster (2002) may provide some degree of perceptual support which aids performance.

The aim of the current experiment is to investigate the effects of using only a single target location on performance in construction and interpretation tasks. It is thought that removal of non-target items may lead to improved performance in the construction condition and that performance with items placed in the Far-Far position in particular may improve due to the child’s ability to place the pointers in an uninterrupted line. Performance on interpretation tasks may also improve in Far-Far trials since there is no requirement to extrapolate lines beyond the first point in a line as in previous studies. By asking the child to place a cup at the location indicated by two pointers, biases that might arise due to selection of one of a number of items will be eliminated. Alternatively, performance on the interpretation task may be affected by the absence of forms of perceptual support, leading to greater difficulty in extrapolating lines and therefore greater inaccuracies in response. This may be apparent in all trial types although the degree of error may be greatest in Far-Far trials since the length of extrapolation may lead to greater scope for error.

Method

Participants

Forty-four children between three years ten months and five years ten months (mean age five years) participated in this study of whom twenty-seven were male and seventeen were female. The children were randomly assigned to one of four conditions such that the mean ages were comparable. The children were taken from the nursery, reception classes and year one of a local primary school. The school was in a predominantly white, middle-class area of Surrey. As the study was to be carried out in the classroom permission was sought from both parents and teachers (see Appendix 1). The children were further divided into two age groups on the basis of whether they were above or below five years old (mean age for the younger group 4 years 6 months approximately, n=23, range= 3 years 10 months- 4 years 10 months; mean age for the older group approximately 5 years, 6 ½ months, n=23, range = 5
years 1 ¼ months – 5 years 10 months). Although a small proportion of the children had participated in a previous experiment, none of the children had participated in any previous experiments in the preceding six months.

Materials

Children were presented with the same 50cm x 50cm sheet of white card mounted on an MDF base as in Studies One and Two. As in the previous studies, two orthogonally placed wooden pointers on a sliding mechanism were set along two sides of the board. The length of the sliding mechanism was divided into six and marked in an unobtrusive way to aid classification of responses. A white Styrofoam cup measuring 5cm in diameter and 3 cm high was used as a ‘hiding place’ in both interpretation and construction conditions. A cardboard teddy measuring 4cm in height was ‘hidden’ inside the cup. The apparatus was placed on the floor to enable the child to look down on it.

Design

Experiment Four consisted of both interpretation and a construction tasks. A multivariate design was used to allow the effects of more than one independent variable to be investigated. As in previous experiments, the between-participants variable of Age (two levels, above or below five years old) and the within-participants variable of Trial Type were included in the design. Additional independent variables included a between-participants factor of Condition. Participants were assigned to one of four conditions. One group performed the construction task followed by an interpretation task. A second group performed the interpretation task followed by the construction task. The third group performed a construction task followed by another construction task and the final group performed the interpretation task followed by another interpretation task. In addition a within-participants factor of Order was included. There were two levels of this factor corresponding to whether the task was the first that the participant performed or the second. These two factors were included in order to ascertain if there were any carryover effects from one task to another. The dependent variable in the interpretation condition was the number of times the child correctly placed the cup at the intersection of the two imaginary lines and was scored according to the two criteria already outlined in Study One. In the construction condition the dependent variable was the number of times the child correctly lined up
the pointers, scored according to the same criteria. Each child completed sixteen trials in each condition.

Procedure

There were two tasks in the experiment. In the interpretation task the children were required to signify the location to which the experimenter was pointing by placing the cup with the teddy inside at that point. The experimenter indicated a point that corresponded to one of the target locations as in Studies One and Two (in the centre of one of the four quadrants on the board) by moving the pointers along the sliding mechanism so the projected lines from the pointers crossed at the correct hiding location. In the construction task the child watched while the experimenter placed the cup with the teddy at one of the four locations and was then required to position the pointers so that imaginary lines projecting from the pointers crossed at the location of the cup.

A counterbalanced design was employed such that approximately one third of the children (n=14) performed the interpretation task followed by the construction task (I-C), approximately one third (n=15) performed the construction task followed by the interpretation task (C-I). The remaining participants formed two further groups, one of which (n=7) performed an interpretation task followed by another interpretation task (I-I), the other (n=8) performing a construction task followed by another construction task (C-C). This design was employed to investigate whether any carry over effects were present and if so, whether they were due to practice or due to a specific task preceding another.

Each child was individually tested in a quiet corner of the classroom. Before the task it was explained to the child that they were going to play a game. In the interpretation task the child was told they were going to play a game called ‘hide the teddy’. The experimenter explained that she was going to point to some where on the board using the pointers and that the child had to hide the teddy in the cup where she was pointing to. During the explanation the experimenter moved the pointers to point to one of the target locations and traced imaginary lines with her fingers. She then explained that the child had to place the teddy where the lines met.

During the construction task the experimenter explained that they were going to play ‘find the teddy’ and that she was going to hide teddy somewhere on the board and that the child had to use the pointers to point to where teddy was hiding. During
the explanation the experimenter hid the teddy as for a Far-Far trial, lined up the
pointers correctly and again drew imaginary lines with her fingers explaining that if
they drew a straight line out from both pointers then where the lines met would be
where teddy was hiding, and that both pointers were pointing to teddy at the same
time. The child was then given the opportunity for two practice trials, one at a Far-Far
location and one at a Near-Near location. The introduction was followed by sixteen
trials. These sixteen trials represented all possible combinations of the four different
hiding places (front-left, front-right, rear-left and rear-right) with the four different
trial types as defined by the distance on each dimension from the pointer (Near-Near,
Near-Far, Far-Near, Far-Far). The trials were presented in a randomised sequence.

In each trial of the construction task the experimenter placed the cup with the teddy
in it on one of the four target locations and then asked the child to use the pointer to
point to where teddy was hiding. If the child responded correctly they were told ‘yes
that’s right’.

In each trial of the interpretation condition the experimenter moved the pointer
from their starting position on the board to point to one of the target locations. The
child was then asked to hide teddy where the experimenter was pointing to. If the
child responded correctly they were told ‘yes, that’s right’.

Results

Results were recorded by marking the location that the child had pointed
to/placed the cup on a six x six grid visible only to the experimenter. For each child,
separate scores reflecting the number of correct responses were taken for each trial
type using both the correct quadrant method of scoring and also the method of scoring
for absolute accuracy. For each child separate scores out of four were taken for each
trial type in each task. Table 5.1 below shows mean scores obtained under the two
scoring systems for each trial type, subdivided into the two factors of condition and
order of performance (Order) used in the study. These results are summarised in
Figures 5.1 to 5.4.

Preliminary screening of the data revealed no significant effects of sex on any
of the recorded variables and so sex was excluded from the analysis. Two four-factor
Trial Type (4) x Order (2) x Condition (4) x Age (2) ANOVAs were carried out with
repeated measures on the first two factors, one for each of the scoring criteria.
Table 5.1. Mean scores per trial type out of four (s.d. in brackets) according to correct quadrant (CQ) and absolute accuracy (AA).

<table>
<thead>
<tr>
<th>Trial Type</th>
<th>Performed First</th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Near-Near</td>
<td>Near-Far</td>
<td>Far-Near</td>
<td>Far-Far</td>
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<td>CQ</td>
<td>AA</td>
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<td>AA</td>
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<td>1.86</td>
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<td>(1.38)</td>
<td>(1.25)</td>
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<td></td>
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<td></td>
<td></td>
<td>(0.00)</td>
<td>(0.89)</td>
<td>(1.13)</td>
<td>(1.53)</td>
</tr>
</tbody>
</table>

Analysis of the data showed that there was no significant main effect of Order according to either criterion. A significant main effect of Age was found according to both criteria, with older children scoring more correct responses than younger ones. \( F(1, 36) = 11.80, p<0.005 \) for the Absolute Accuracy criterion and \( F(1, 36) = 5.27, p<0.05 \) for the Correct Quadrant Criterion. (see Figure 5.1).

There was also a significant main effect of Trial Type for both criteria (\( F(3,108) = 49.03, p<0.001 \) for Absolute Accuracy; \( F(3,108) = 23.06, p<0.001 \) for Correct Quadrant), the number of correct responses indicating that, overall Near-Near trials...
were easier in comparison to other categories. Far-Far trials were hardest and Near-Far and Far-Near trials of intermediate level of difficulty (see Figures 5.2a and 5.2b). A significant effect of Condition was also evident according to both Absolute Accuracy (AA) and Correct Quadrant (CQ) criteria (F (3,36) =5.20, p<0.005; F (3,36) =5.65, p<0.005) respectively. Scores on the Interpretation-Interpretation condition were poorer than those on any other (p<0.05). Performance on construction tasks was superior to that on interpretation tasks. (see Figure 5.3)

In addition to significant main effects of Condition, Trial Type and Age according to both criteria, significant interactions between Trial Type x Age (F (3,108) =3.25, p<0.05 for AA, F (3,108) =3.72, p<0.05 for CQ) and Condition x Order (F (3,36) =12.88, p<0.001 for AA, F (3,36) =10.56, p<0.001 for CQ) were noted for both criteria. The Condition x Order interaction appears to reflect a superiority on the construction task compared with the interpretation task (See Figures 5.4 and 5.5). Examination of the Trial Type x Age effect suggests that differences in performance between older and younger children are greater in Far-Near and Far-Far trials.

**Figure 5.1** Mean number of correct responses out of sixteen for two age groups using two scoring criteria
A significant Trial Type x Condition interaction (F (9, 36) = 2.95, p < 0.01) exists according to the Correct Quadrant criterion. Children showed no effect of condition upon performance on Near-Near trials whereas differences were apparent in other trial types. An Order x Condition x Trial Type interaction (F (9,108) = 4.60, p < 0.001) was also evident according to the CQ criterion, children display poorer performance on Far-Far trials in the interpretation task in comparison with the construction task, and an Order x Condition x Age interaction (F (3,36) = 5.94, p < 0.005). Younger children appear to show superior performance on the construction task compared to the interpretation task regardless of its order or what has preceded it whereas older children show improved performance on the second task except in the Interpretation-Interpretation condition.

An Order x Trial Type x Condition x Age interaction was also present according to the Absolute Accuracy criterion (F (9,108) = 2.39, p < 0.05). In addition to the above effects, scores according to the Correct Quadrant (CQ) criterion were found to be significantly higher than those according to the Absolute Accuracy (AA) criterion (T = 10.61, p < 0.001, one tailed with 43 df). Younger children showed a greater difference in scores according to the two scoring criteria. Younger children had on average 8.63 correct response according to the AA criterion and 13.43 according to the CQ criterion whereas older children had average scores of 12.31 and 14.74 respectively (t = 3.98, p < 0.001, one tailed with 42 df).
Figure 5.2a: Mean number of correct responses (out of 4) for each trial type using the Correct Quadrant (CQ) criterion.

![Graph showing mean number of correct responses using the Correct Quadrant (CQ) criterion.]

Figure 5.2b: Mean number of correct responses (out of 4) for each trial type using Absolute Accuracy (AA) criterion.

![Graph showing mean number of correct responses using the Absolute Accuracy (AA) criterion.]

Figure 5.3: Mean number of correct responses (out of sixteen) in construction and interpretation conditions using Correct Quadrant (CQ) and Absolute Accuracy (AA) criteria.

Figure 5.4a: Mean number of correct responses (out of sixteen) in first and second tasks under different task orders (CQ)
Figure 5.4b: Mean number of correct responses (out of sixteen) in first and second tasks under different task orders (AA)

Error analysis

Errors were coded in terms of errors on the Near-Far and the left-right dimensions. The majority of errors in both interpretation and construction conditions consisted of small errors on one or both dimensions. Larger errors locating a space outside the correct quadrant were more prevalent in the interpretation condition (39.2% of the errors in the interpretation condition which did not involve placing the cup next to the pointer compared to 11.8% of the errors in the construction condition). The majority of errors, 70.8% in the construction condition and 91.2% in the construction condition were in line with one or other of the markers. In the interpretation condition 19% of the errors were made by the child placing the cup immediately adjacent to one of the markers. Approximately 63% of these errors were made by the younger children.

Comparison Between Construction Task and Study One

Performance on each trial type in the construction task in this study (n=37) was compared to that in Study One (n=84) by means of independent t-tests.
Performance on all trial types was superior in this study according to the CQ criterion (N-N $t=2.87$, 119d.f., $p<0.01$, 2-tailed; N-F $t=3.78$, 119d.f., $p<0.001$, 2-tailed; F-N $t=3.23$, 119d.f., $p<0.005$, 2-tailed; F-F $t=3.55$, 119d.f., $p<0.001$, 2-tailed).

Performance was also superior on all trial types, with the exception of Far-Far trials, according to the AA criterion (N-N $t=3.84$, 119d.f., $p<0.001$, 2-tailed; N-F $t=2.94$, 119d.f., $p<0.005$, 2-tailed; F-N $t=2.17$, 119d.f., $p<0.05$, 2-tailed).

**Discussion**

Results from this experiment show that trial type effects persist despite the absence of distractor items which may have interfered with the ability to extrapolate lines beyond these intervening items or lead to biases in responding by the selection of objects nearest to one or other of the markers. This difference exists in both construction and interpretation tasks; performance is poorest in Far-Far trials and superior in Near-Near trials. The difference in performance between trial types is most marked in interpretation tasks where scoring takes into account the accuracy of the response (AA criterion) with performance on Far-Far trials being very poor in this instance.

Performance in the construction task in the current study is superior to that in Study One according to both the absolute accuracy and the correct quadrant criteria, although this difference did not reach significance in the case of Far-Far trials using the absolute accuracy criteria. As the sole difference between the two tasks is the absence of any distracting items. It appears that this is the most likely reason for this improved performance. This may be due to the fact that there are no objects blocking the lines of projection between the pointers and the object to which they are pointing. Children in the earlier construction task in Study One were often noted placing the pointers in such a way that there was an uninterrupted line between the pointer and the target cup. However improvement did not only occur in Near-Far, Far-Near and Far-Far trials where the presence of the extra cups may have had a masking effect but also on Near-Near trials where performance on Near-Near trials was very near ceiling. This suggests that the presence of the other cups on the board has an effect other than just blocking the path of a perpendicular line towards the target.

Although relatively few errors were made on the Near-Near trials in Study One, a sizeable number of these errors can be classified as pointing to a cup other than
the target cup. It may be that young children were making errors because they were becoming confused or losing track of which cup the teddy was hidden under. There is no scope for such errors in the current study and this may be responsible for some of the improvement in performance, particularly that seen in the Near-Near trials.

Performance in the interpretation task was inferior to that in Study Two overall. Mean scores in the Study Two interpretation task were greater across all trial types than those in this study according to the absolute accuracy criterion and performance was considerably poorer in Far-Far trials in the current experiment although ability to choose a location in the correct quadrant of the board was greater, across most trial types, than the ability to choose the correct cup in Study Two. This result suggests that when the other cups are removed, children are able to identify the approximate area a cup should fall within and that children’s errors in the interpretation tasks in previous studies (Lidster & Bremner, 1999; Lidster, 2002) may be due, in part, to the presence of the other cups on the board leading to biases in responding. This is supported by the presence of the ‘search next to pointer’ strategy evident in previous studies (Bremner et al. 1993).

Fine-timing to an exact location, however, appears to be a problem. This may be due to difficulties in extrapolating lines and may have been made more difficult by the removal of most forms of perceptual support that had been present in previous experiments despite Blades & Spencer’s (1989) finding that the provision of grid lines had no effect on performance in their study. Performance on Far-Far trials was particularly poor and this may be a result of the requirement to extrapolate lines over greater distances. Bryant and Somerville (1986) suggest that six-year-olds show greater accuracy extrapolating lines over shorter distances than longer ones.

It was noted that in the interpretation condition some children made errors of placing the cup next to one or other of the pointers (see Figure 5.5) suggesting that, whilst aiming to eliminate the tendency to select a cup next to one of the markers by simplifying the design, the same error persists when placing the cup. Children appear to be interpreting the cues to location based on principles of proximity. This is consistent with Piaget & Inhelder’s (1961) conjecture that until around the age of eight or nine years, young children cannot code location according to Euclidean principles and that early spatial coding in children is topological in nature. In addition, placing the cup next to one of the pointers supports the suggestion by both Piaget &
Inhelder (1961) and Sandberg, Huttenlocher & Newcombe (1996) that young children experience problems in considering more than one dimension simultaneously.

The tendency to place the cup next to one of the pointers was more prevalent in younger children than in older children, supporting Piaget & Inhelder’s (1961) and Sandberg et al.’s (1996) suggestion that children progress developmentally from consideration of one dimension only to consideration of two.

**Figure 5.5:** Example of type of error, placing cup next to marker on interpretation condition.

![Figure 5.5](image)

**Figure 5.6:** Example of type of error, placing cup on imaginary line between two pointers

Another type of error noted was the strategy of placing the cup at a point on a line connecting the two markers (see Figure 5.6). The presence of this type of error suggests that some children are using principles of projection rather than Euclidean space in their interpretation of cues to location and again supports Piaget & Inhelder’s view regarding the development of spatial coding. According to Piaget & Inhelder (1961), children progress from topological coding of space based on proximity to cues.
to location to projective coding, based on lines of projection from cues to location and finally Euclidean coding. Both of the above error types support the view that whereas many children are capable of interpreting orthogonally placed markers, there are still some children for whom this is problematic and whose interpretation of location cues may be guided by principles of proximity and projection (Piaget & Inhelder, 1956).

**Summary of findings**

This study examined the effects of the removal of distractor items on construction and interpretation of spatial coordinates. In the construction task children had to use orthogonally placed pointers to construct spatial coordinates for a single cup placed at different locations on a board and in the interpretation task children had to place a single cup at a location indicated by orthogonally placed markers.

The removal of the additional cups which may have acted as distractors was shown to lead to an improvement in performance on both construction and interpretation tasks according to the Correct Quadrant criterion suggesting that performance on these tasks may, in part, be affected by biases and errors caused by the presence of objects other than that at the target location. However, performance according to the Absolute Accuracy criterion was much poorer in the interpretation task and it is thought that lack of perceptual support may play a part in this.

As in all previous studies in this thesis strong age effects were found with younger children performing more poorly than older children. This effect was stronger when results were assessed according to the Absolute Accuracy criterion suggesting accuracy is strongly affected by age.

Trial type effects persisted in both tasks with performance being superior in Near-Near tasks and poorest in Far-Far tasks, consistent with earlier studies (Lidster & Bremner, 1999; Lidster, 2002; Experiment 1). This appears strongest in the interpretation task with scores on the Far-Far trials being very poor, particularly according to the Absolute Accuracy criterion. In order to explore the role that the distance of extrapolation has on these results, the next study aims to look at the effect of reducing the scale of the task.
Chapter 6: Study Five

The effect of scale on young children’s ability to use coordinate dimensions.

Introduction

The results from Study Four indicate that differences in performance between trial types persist despite removing some of the possible sources of error and bias. Although performance on construction tasks is improved following the removal of possible distractors, removing the opportunity to choose between one of four possible cups seems to make the interpretation task much harder and suggests that perhaps by removing this framework and allowing the child free choice in interpreting the coordinates, the task demands are much greater. Most previous research has relied upon presenting the child with a number of options to choose from when completing the interpretation task, perhaps overestimating the child’s ability to interpret Euclidean coordinates. Nevertheless the advantage on Near-Near trials in comparison to other trials persists even when scoring responses for absolute accuracy. This study aims to explore the reasons for this.

Differences in performance between trial types.

Lidster & Bremner (1999) found a main effect of trial type with performance superior on Near-Near problems and poorest on Far-Far problems with intermediate performance on Near-Far trials. This effect of trial type has also been found in the present studies although the effect of trial type appears to be mediated by the task demands and also the scoring system.

The explanations for this effect of trial type could include problems in reaching across the equipment and difficulty in extrapolating lines over greater distance. Somerville & Bryant (1985) found that when children were asked to indicate which of several dots were indicated in two types of coordinate tasks, the hardest problems were those involving extrapolation over the greater absolute distance and that tasks that involved extrapolation past the first point in line with a marker were also harder. Bryant & Somerville (1986) also found a significant effect of length of extrapolation when children were asked to indicate a point on either an axis or a
function line that corresponded to a given point on either the function line or the axis respectively. Children showed a greater degree of error away from the correct point when the distance over which they had to extrapolate was 90mm compared to 60mm. They also found an effect of age suggesting that older children were more accurate than younger ones and that the distance over which they had to extrapolate had less of an effect.

The effect of scale in spatial tasks.

The size of the space involved in spatial tasks has been found to be an important factor with regard to performance on these tasks. One finding is that different sized environments give rise to different strategies for dealing with the location of objects within the space (Learmonth, Newcombe & Huttenlocher, 2001). In addition, larger spaces may give rise to difficulties extrapolating over larger distances as in the above studies. However, Lidster (2002, Experiment Six) reports superior performance in spatial transfer tasks which contained ‘larger’ elements (a 100cm x 100cm board) as opposed to those that contained only ‘smaller’ elements (50cm x 50cm board).

Somerville & Bryant (1985) presented children with a variety of tasks requiring the interpretation of spatial coordinates. In their study children were presented with tasks involving the use of a large board as well as a smaller scale pencil and paper task. The tasks involving the larger equipment revealed an effect of absolute distance from the pointer, which was not present in the pencil and paper task suggesting that this effect may be related to the size of the materials.

Subdivision of space.

As stated earlier in Chapter One, Huttenlocher, Newcombe & Sandberg (1994) suggest that developmental differences occur in the ability to subdivide space and that spatial location is coded increasingly hierarchically with age. Whereas Sandberg, Huttenlocher & Newcombe (1996) suggest that the subdivision of space becomes increasingly fine-grained with age, there is also evidence that the age at which children impose subdivisions upon a space is dependent upon the size of the enclosed area. Huttenlocher, Newcombe & Sandberg (1994) looked at patterns of response bias in three groups of children (four to five years old; six to seven years old and ten to eleven years old) on a pencil and paper task (20cm long x 4cm wide) compared with
performance on a sandbox (60 inches long x 16 inches wide) task and found evidence to suggest that even the youngest group subdivided the area in the pencil and paper task into two halves. This subdivision was not seen in the sandbox task until the age of six. They suggest that ‘subdivision seems to emerge initially where location is coded along only one dimension, or where the scale of the bounded space is small as in the rectangle.’

**Aims of this study**

Although both Somerville & Bryant (1985) and Huttenlocher et al. (1994) both report differences between tasks, which they attribute to the effect of size, there is equally a possibility that the differences, attributed scale, arise due to fundamental differences between the tasks involved. Huttenlocher et al. (1994) compared the performance of four to ten year old children on a task requiring them to point to a location from memory in a large sandbox to that where they were required to recreate the position of a point within a small scale drawing of a rectangle by drawing it on a blank rectangle. Although no comparison of accuracy is given, previous research suggests that children’s pointing responses are a relatively accurate way of indicating location compared to other methods (Lehnung, Haaland, Pohl & Leplow, 2001). In addition Huttenlocher et al. (1994) found a large number of ‘mirror-image’ responses occurring in the younger age groups during the pen and paper task, which were not evident during the sandbox study. These were prevalent enough for Huttenlocher et al. to discard some of the responses of the six year olds and to amend their scoring procedure for the youngest age group, suggesting that the two tasks may have been making different demands upon the children. Somerville & Bryant (1985) found an effect due to absolute distance between pointers and target in their picture task but not their pen and paper task, which they attribute to size of the equipment. However, although perhaps not as marked as the differences between the tasks compared, by Huttenlocher et al. (1994), it is possible that these differences may have arisen due to aspects such as mode of response (pointing versus marking with a pencil) or the nature of the stimulus material (drawings versus slides) used in these studies rather than scale alone.

This study aims to explore the effect of scale by comparing children’s performance on equivalent tasks where the only difference lies in the size of the equipment being used. Of interest is whether differences between trial types persist.
despite reducing the need to extrapolate over larger distances. Such differences did not persist in the findings of Somerville & Bryant (1985) on the pencil and paper task and so if their conjecture that this is due to the size of the area the point is located in is true, we would expect the effect of distance from the pointers to be eliminated through use of a smaller task as in their study. Also of interest is the degree to which to which the space is subdivided. If, as Huttenlocher et al. (1994) suggest, the subdivision of space is affected by the size of the space involved, we might reasonably expect the children to show greater subdivision of space in a scaled-down version of Study Three. This would be reflected in scores that were equal to or perhaps even better than those in Study Three and younger children should show greater subdivision of space than in Study Three.

Method

Participants

Fifty-nine children between four years three months and five years ten months (mean age five years three months) participated in this study of whom thirty-seven were male and twenty-two were female. The children were randomly assigned to one of four conditions as in Study Four such that the mean ages were comparable. One third of the children performed the interpretation task followed by the construction task (I-C, n=21); one third performed the construction task followed by the interpretation task (C-I, n=20). The remaining participants formed two further groups, one of which performed an interpretation task followed by another interpretation task (I-I, n=9), the other performing a construction task followed by another construction task (C-C, n=9). The children were taken from the nursery, reception classes and year one of a local primary school. The school was in a predominantly white, middle-class area of Surrey. As the study was to be carried out in the classroom permission was sought from both parents and teachers (see Appendix 1). The children were further divided into two age groups on the basis of whether they were above or below the mean age (mean age for the younger group 5 years, n=32, range = 4 years 3 months- 5 years 3 months; mean age for the older group five years seven months, n=27, range = 5 years 3½ months- 5 years 10 months). Although some of the children had participated in a previous experiment, none had taken part in the preceding six months.
**Materials**

Children were presented with a 25cm x 25cm sheet of white card mounted on an MDF base. This meant that each side of the card was one half the size of that in Study Four, giving an overall area one quarter of that in Study Four (See Figure 6.1). As in the previous studies, two orthogonally placed wooden pointers on a sliding mechanism were set along two sides of the board. The length of the sliding mechanism was divided into six and marked in an unobtrusive way to aid classification of responses. A white cup, scaled appropriately to be one half the diameter (2.5cm) and half the height (1.5 cm) was used as a 'hiding place' in both interpretation and construction conditions. A teddy sticker was 'hidden' inside the cup. The apparatus was placed on the floor to enable the child to look down on it.

**Figure 6.1:** Comparison of equipment used in Study Four (left) and Study Five (right)

**Design**

The design of the experiment was identical to that of the single item design used in Study Four. As in Study Four there were two levels of the between-participants independent variable **Age** (above or below five years three months) and
four levels of the between-participants independent variable **Condition** (Construction-Construction, Construction-Interpretation, Interpretation-Interpretation, Interpretation-Construction) included to investigate whether there were any carryover effects from one task to another. Within-participant variables again included **Trial Type** (four levels) and **Order** (two levels). In addition, comparison of Studies four and five allowed the effects of a further between-participants variable, **Study** to address the effect that differences in scale between the two studies may have had. As in Study Four, there were two tasks in the experiment. In the interpretation task the children were required to signify the location to which the experimenter was pointing by placing the cup with the teddy inside at that point. The experimenter indicated a point that corresponded to one of the target locations in the centre of one of the four quadrants on the board by moving the pointers along the sliding mechanism so the projected lines from the pointers crossed at the correct hiding location. In the construction task the child watched while the experimenter placed the cup with the teddy at one of the four locations and was then required to position the pointers so that imaginary lines projecting from the pointers crossed at the location of the cup.

A counterbalanced design was employed such that one third of the children performed the interpretation task followed by the construction task (I-C, n=21); one third performed the construction task followed by the interpretation task (C-I, n=20). The remaining participants formed two further groups, one of which performed an interpretation task followed by another interpretation task (I-I, n=9), the other performing a construction task followed by another construction task (C-C, n=9). This design was employed to investigate whether any carry over effects were present and if so, whether they were due to practice or due to a specific task preceding another. The dependent variable in the interpretation condition was the number of times the child correctly placed the cup at the intersection of the two imaginary lines and was scored according to the two criteria already outlined in Study One. In the construction condition the dependent variable was the number of times the child correctly lined up the pointers, scored according to the same criteria.

Each child completes sixteen trials in each condition.

**Procedure**

Each child was individually tested in a quiet corner of the classroom. Before the task it was explained to the child that they were going to play a game. In the
In the interpretation task the child was told they were going to play a game called 'hide the teddy'. The experimenter explained that she was going to point to somewhere on the board using the pointers and that the child had to hide the teddy in the cup where she was pointing to. During the explanation the experimenter moved the pointers to point to one of the target locations and traced imaginary lines with her fingers. She then explained that the child had to place the teddy where the lines met.

During the construction task the experimenter explained that they were going to play 'find the teddy' and that she was going to hide teddy somewhere on the board and that the child had to use the pointers to point to where teddy was hiding. During the explanation the experimenter hid the teddy as for a Far-Far trial, lined up the pointers correctly and again drew imaginary lines with her fingers explaining that if they drew a straight line out from both pointers then where the lines met would be where teddy was hiding and that both pointers were pointing to teddy at the same time. The child was then given the opportunity for two practice trials, one at a Far-Far location and one at a Near-Near location.

The introduction was followed by sixteen trials. These sixteen trials represented all possible combinations of the four different hiding places (front-left, front-right, rear-left and rear-right) with the four different trial types as defined by the distance on each dimension from the pointer (Near-Near, Near-Far, Far-Near, Far-Far). The trials were presented in a randomised sequence.

In each trial of the construction task the experimenter placed the cup with the teddy in it on one of the four target locations and then asked the child to use the pointer to point to where teddy was hiding. If the child responded correctly they were told 'yes that's right'.

In each trial of the interpretation condition the experimenter moved the pointer from their starting position on the board to point to one of the target locations. The child was then asked to hide teddy where the experimenter was pointing to. If the child responded correctly they were told 'yes, that's right'.

Results

Results were recorded by marking the location that the child had pointed to/placed the cup on a six x six grid visible only to the experimenter. For each child, separate scores reflecting the number of correct responses were taken for each trial type using both the correct quadrant method of scoring and also the method of scoring
for absolute accuracy. For each child separate scores out of four were taken for each trial type in each task. Table 6.1 below shows mean scores obtained under the two scoring systems for each trial type, subdivided into the two factors of condition and order of performance (Order) used in the study. These data are also summarised in Figures 6.2 to 6.5.

**Table 6.1:** Mean scores per trial type out of four (s.d. in brackets) according to correct quadrant and absolute accuracy.

<table>
<thead>
<tr>
<th>Performed First</th>
<th>Near-Near</th>
<th>Near-Far</th>
<th>Far-Near</th>
<th>Far-Far</th>
<th>Total (/16)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CQ</td>
<td>AA</td>
<td>CQ</td>
<td>AA</td>
<td>CQ</td>
</tr>
<tr>
<td>Construct-Construct</td>
<td>3.89</td>
<td>(0.33)</td>
<td>3.56</td>
<td>(0.53)</td>
<td>3.78</td>
</tr>
<tr>
<td>Construct-Interpret</td>
<td>4.00</td>
<td>(0.00)</td>
<td>3.85</td>
<td>(0.37)</td>
<td>4.00</td>
</tr>
<tr>
<td>Interpret-Interpret</td>
<td>4.00</td>
<td>(0.00)</td>
<td>2.89</td>
<td>(1.45)</td>
<td>3.22</td>
</tr>
<tr>
<td>Interpret-Construct</td>
<td>3.86</td>
<td>(0.36)</td>
<td>3.05</td>
<td>(1.36)</td>
<td>3.10</td>
</tr>
<tr>
<td>Performed Second</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construct-Construct</td>
<td>4.00</td>
<td>(0.00)</td>
<td>3.89</td>
<td>(0.33)</td>
<td>4.00</td>
</tr>
<tr>
<td>Interpret-Construct</td>
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<td>(0.78)</td>
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<td>(0.22)</td>
<td>2.85</td>
<td>(1.42)</td>
<td>3.45</td>
</tr>
</tbody>
</table>

Initial screening of the data revealed no significant sex differences across response variables and so sex was omitted from the analysis. In order to gauge the effect of the two different scoring criteria on the results, two separate analyses were...
carried out, one for each scoring criteria. Two four-factor, Trial Type (4) x Order (2) x Condition (4) x Age (2) ANOVAs were carried out with repeated measures on the first two factors. Analysis of the data revealed a main effect of type according to both criteria (F(3,153) = 14.91, p<0.001 for correct quadrant and F(3,153) = 61.93, p<0.001 for absolute accuracy) (see Figures 6.2a and b and 6.3a and b). As in previous studies Near-Near trials showed the greatest number of correct responses and Far-Far trials the least. There were no main effects according to either the correct quadrant or the absolute accuracy criterion for Age, Order, or Condition.

A significant interaction was found between Order and Condition according to both criteria (F(3, 51) = 17.23, p<0.001 for absolute accuracy and F(3, 51) = 7.73, p=0.01 for correct quadrant). This appears to be a reflection of the superiority on the construction task (see Figures 6.4 and 6.5) whereby performance on the first task is superior on the construction-interpretation condition and performance on the second task is superior in the interpretation-construction condition. In addition a significant 3-way interaction was also found between Order, Condition and Type (F(9,153) = 3.28, p<0.005) for the correct quadrant criteria and a significant four-way interaction between Order, Condition, Type and Age (F(3, 153) = 2.21, p<0.005) for the Absolute Accuracy criterion.

**Error analysis**

As in the previous studies error analysis was carried out. Responses were coded in terms of the amount of left-right and Near-Far error present. Overall the majority of errors in both the construction and interpretation tasks consisted of small deviations on either the Near-Far or left-right dimension. Large errors (which located a point in space outside of the target quadrant) were more common in the younger age group suggesting that accuracy improves with age. These types of errors were also very much more prevalent in the interpretation condition than the construction condition. Very few of the errors in the construction condition located a point outside the target quadrant (5.3%) whereas this was a common error type in the interpretation condition (34.6%) and yet again more common among younger children.

In the interpretation condition the majority of errors on both dimensions occurred in Far-Far trials and the majority of large errors on a single dimension occurred in the Near-Far and Far-Near trials suggesting that some children may only be capable of focussing on one dimension at a time. Further examination of the results
suggests that some of these errors in the interpretation condition can be accounted for by the child placing the cup next to one of the pointers. This can also explain some of the one-dimensional errors.

In addition to differences in errors between age groups and task conditions there was also evidence that different types of error were more prevalent according to trial type. Far-Far trials showed the greatest number of errors on both dimensions in both interpretation and construction conditions although this was most notable in the interpretation condition. In addition Near-Near trials showed the fewest number of responses classified by errors on both dimensions which indicated a location outside the target area.
Figures 6.2a and 6.2b Mean number of correct responses (out of 4) in the construction condition (a) and the interpretation condition (b) using the Correct Quadrant criterion.

Figures 6.3a and 6.3b Mean number of correct responses (out of 4) in the construction condition (a) and interpretation condition (b) using the Absolute Accuracy criterion.
**Figure 6.4:** Mean number of correct responses in first and second tasks under different task orders- absolute accuracy

![Bar chart showing mean number of correct responses in first and second tasks under different task orders.](image)

**Figure 6.5:** Mean number of correct responses in first and second tasks under different task orders- correct quadrant

![Bar chart showing mean number of correct responses in first and second tasks under different task orders.](image)
Comparison of Studies Four and Five

Both Studies Four and Five involved the same construction and interpretation tasks. However in Study Five the size of the equipment was scaled down so that the overall area was one quarter of that in Study Four. This allows the effects of scale to be investigated.

Data from Studies Four and Five were combined to allow a comparison of correct responses and error types, in order to investigate the effects of scale on young children’s performance. As the mean ages of the two groups were slightly different it was decided to combine the groups and to classify them into two age groups on the basis of whether they were above or below the new group mean of five years and two months (n=45, mean = four years eight months for younger group, n=58, mean =five years six months for the older age group). This meant that two children from the older group in Study Four were now classified in the younger group and seven children who were classified as being in the younger group in Study Five were now classified as being in the older group. These children were retained in the sample as initial screening suggested that excluding them would have little impact on the main order effects and interactions between the factors.

Table 6.2 shows the mean scores for each trial type according to task order for each of the conditions of Studies Four and Five. These results are also summarised in Figures 6.6 to 6.9. Two five-factor, Trial Type (4) x Order (2) x Condition (4) x Age (2) x Study (2) ANOVAs were carried out with repeated measures on the first two factors.

Analysis of the data revealed a main effect of Type according to both the Correct Quadrant and the Absolute Accuracy criteria (F (3,261) =36.67, p<0.001 and 105.91, p<0.001 respectively). As found previously, in the individual analyses, near- near trials are the easiest and Far-Far the hardest with intermediate levels of performance on Far-Near and Near-Far trials (see Figure 6.10).
Table 6.2. Mean scores per trial type out of four (s.d. in brackets) according to correct quadrant and absolute accuracy for Studies 4 and 5.

<table>
<thead>
<tr>
<th>Performed First</th>
<th>Near-Near</th>
<th>Near-Far</th>
<th>Far-Near</th>
<th>Far-Far</th>
<th>Total (/16)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CQ</td>
<td>AA</td>
<td>CQ</td>
<td>AA</td>
<td>CQ</td>
</tr>
<tr>
<td>4. Construct-Construct</td>
<td>4.00</td>
<td>3.87</td>
<td>3.87</td>
<td>3.75</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.35)</td>
<td>(0.35)</td>
<td>(0.46)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>5. Construct-Construct</td>
<td>3.89</td>
<td>3.56</td>
<td>3.78</td>
<td>2.33</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>(0.33)</td>
<td>(0.53)</td>
<td>(1.10)</td>
<td>(1.10)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>4. Construct-Interpret</td>
<td>4.00</td>
<td>3.93</td>
<td>3.67</td>
<td>2.93</td>
<td>3.80</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.26)</td>
<td>(1.05)</td>
<td>(1.16)</td>
<td>(0.56)</td>
</tr>
<tr>
<td>5. Construct-Interpret</td>
<td>4.00</td>
<td>3.85</td>
<td>4.00</td>
<td>3.30</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.37)</td>
<td>(0.00)</td>
<td>(0.78)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>4. Interpret-Interpret</td>
<td>4.00</td>
<td>2.71</td>
<td>2.71</td>
<td>2.00</td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(1.68)</td>
<td>(1.38)</td>
<td>(1.53)</td>
<td>(1.40)</td>
</tr>
<tr>
<td>5. Interpret-Interpret</td>
<td>4.00</td>
<td>2.89</td>
<td>3.22</td>
<td>1.89</td>
<td>3.56</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(1.45)</td>
<td>(1.09)</td>
<td>(1.69)</td>
<td>(0.73)</td>
</tr>
<tr>
<td>4. Interpret-Construct</td>
<td>3.93</td>
<td>2.79</td>
<td>3.29</td>
<td>2.00</td>
<td>3.07</td>
</tr>
<tr>
<td></td>
<td>(0.27)</td>
<td>(1.48)</td>
<td>(0.73)</td>
<td>(1.62)</td>
<td>(1.21)</td>
</tr>
<tr>
<td>5. Interpret-Construct</td>
<td>3.86</td>
<td>3.05</td>
<td>3.10</td>
<td>2.19</td>
<td>3.33</td>
</tr>
<tr>
<td></td>
<td>(0.36)</td>
<td>(1.36)</td>
<td>(1.34)</td>
<td>(1.57)</td>
<td>(0.97)</td>
</tr>
<tr>
<td>Performed Second</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>4.00</td>
<td>3.63</td>
<td>3.88</td>
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<tr>
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<td>(0.35)</td>
<td>(0.00)</td>
<td>(0.52)</td>
<td>(1.07)</td>
</tr>
<tr>
<td>5. Construct-Construct</td>
<td>4.00</td>
<td>3.89</td>
<td>4.00</td>
<td>2.89</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.33)</td>
<td>(0.00)</td>
<td>(0.78)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>4. Interpret-Construct</td>
<td>4.00</td>
<td>3.93</td>
<td>3.93</td>
<td>3.21</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
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<td>(0.27)</td>
<td>(0.27)</td>
<td>(0.89)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>5. Interpret-Construct</td>
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<td>3.90</td>
</tr>
<tr>
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<td>(0.78)</td>
<td>(0.30)</td>
<td>(0.91)</td>
<td>(0.30)</td>
</tr>
<tr>
<td>4. Interpret-Interpret</td>
<td>3.71</td>
<td>2.71</td>
<td>2.71</td>
<td>1.86</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>(0.49)</td>
<td>(1.38)</td>
<td>(1.25)</td>
<td>(1.57)</td>
<td>(1.15)</td>
</tr>
<tr>
<td>5. Interpret-Interpret</td>
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<td>3.33</td>
<td>3.11</td>
<td>2.22</td>
<td>3.44</td>
</tr>
<tr>
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<td>(1.32)</td>
<td>(1.36)</td>
<td>(1.92)</td>
<td>(1.04)</td>
</tr>
<tr>
<td>4. Construct-Interpret</td>
<td>4.00</td>
<td>3.07</td>
<td>3.13</td>
<td>2.07</td>
<td>2.93</td>
</tr>
<tr>
<td></td>
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<td>(0.89)</td>
<td>(1.13)</td>
<td>(1.53)</td>
<td>(1.10)</td>
</tr>
<tr>
<td>5. Construct-Interpret</td>
<td>3.95</td>
<td>2.85</td>
<td>3.45</td>
<td>2.15</td>
<td>3.33</td>
</tr>
<tr>
<td></td>
<td>(0.22)</td>
<td>(1.42)</td>
<td>(0.94)</td>
<td>(1.31)</td>
<td>(0.98)</td>
</tr>
</tbody>
</table>
Figure 6.6: Mean scores in first task (out of four) according to trial type and task order (Correct Quadrant).

Figure 6.7: Mean scores in first task (out of four) according to trial type and task order (Absolute Accuracy).
Figure 6.8: Mean scores (out of four) in second task according to trial type and task order (Correct Quadrant).

Figure 6.9: Mean scores (out of 4) in second task according to trial type and task order (Absolute Accuracy).
Figure 6.10a and b: Mean number of correct scores (out of eight) for each trial type according to the Correct Quadrant (a) and Absolute Accuracy (b) scoring criteria.

(a)

(b)

In addition both criteria revealed a main effect for condition ($F(3, 87) = 7.47$, $p<0.001$ for CQ and $F(3, 87) = 5.25$, $p<0.005$ for AA, see Figures 6.11 and 6.12). There were no main effects of Order or Study for either criterion. A main effect for Age ($F(1, 87) = 7.12$, $p<0.01$) was found using the Absolute Accuracy criterion only with older children performing better than younger ones.

An Order x Condition interaction was apparent according to both criteria ($F(3, 87) = 14.81$, $p<0.001$ for CQ and 26.63, $p<0.001$ for AA). This seems to reflect the superiority of performance on construction tasks over interpretation tasks (see Figures 6.6 and 6.7). Other interactions revealed were significant interactions between Type and Condition according to the CQ criteria ($F(9,261)= 5.65$, $p<0.001$). This interaction between Trial Type and Condition appears to reflect the poorer overall performance on all trial types except Near-Near trials, and especially Far-Far trials, during interpretation tasks (see Figures 6.11 and 6.12). Interactions between Type and Study ($F(3,261) = 4.10$, $p<0.01$, see Figure 6.13) and Type and Age ($F(3,261) =4.10$, $p<0.01$, see Figure 6.14) are apparent for the AA criteria. Differences in performance between the studies exist on Far-Near and Far-Far trials with children performing better on the scaled down version. Younger children perform more poorly than older children and these differences are more marked in Far-Far trials and less substantial in Near-Near trials.
Figure 6.11: Mean number of correct responses (out of sixteen) in first and second tasks by condition (task order) using the Correct Quadrant scoring criterion

![Bar chart showing mean number of correct responses for different conditions and tasks using the Correct Quadrant scoring criterion.]

Task order

Figure 6.12: Mean number of correct responses (out of sixteen) in first and second tasks by condition (task order) using the Absolute Accuracy criterion

![Bar chart showing mean number of correct responses for different conditions and tasks using the Absolute Accuracy scoring criterion.]

Task order
Additionally, three-way interactions between Type, Order and Condition (F (9,261) = 7.26, p<0.001) and Order, Condition and Age (F (3,261)=3.07, p<0.05) were present according to the CQ criterion as were two, four-way interactions between Type, Age, Condition and Study (F (9,261)=2.31,p<0.05) and Type, Age, Condition and Order (F (9,261)= 2.17,p<0.05). A five way Type x Order x Study x Age x Condition interaction was present according to the AA criteria (F (9,261) =2.12, p<0.05).

**Figure 6.13:** Mean number of correct responses (out of eight) for different trial types by study (AA)
Summary of results

Analysis of results of Study Five show that there is a significant effect of trial type and that performance on Near-Near trials is superior to that on Far-Far trials. An advantage of the construction task over the interpretation task is also evident according to both criteria. There is no significant effect of age apparent in this study. Analysis of the data according to the correct quadrant criteria reveals that the difference in performance on construction and interpretation tasks is most marked on Far-Far trials.

Comparison of the results between Studies Four and Five revealed no effect due to study (scale). The main effect of type apparent in the individual analyses of these studies was again present. A main effect of age was apparent only when assessing performance in terms of absolute accuracy. There was no evidence of a significant carry-over effect. Performance on the second task did not appear to be affected by the nature of the first task nor was there evidence for an order effect. Performance on the first and second tasks did not differ significantly.

Discussion

Results of Study Five suggest that a trial type effect persists even following the removal of distractor items and the reduction of the necessity to extrapolate lines.
over large distances. Examination of the results suggests that this trial type effect primarily occurs in the interpretation task. Performance in the construction task is fairly uniform across trial types if assessed according to the correct quadrant criteria, approaching ceiling even on Far-Far trials. However if responses are assessed according to the absolute accuracy criteria then the effect is apparent in the construction task as well as the interpretation task. These findings of differences according to trial type are consistent with those of Lidster & Bremner, 1999 and Lidster, 2002 as well as the earlier studies within this sequence (Study One).

However, it is notable that differences according to trial type appear to be absent according to the CQ criteria in the construction condition using the scaled down materials suggesting that when the distances are reduced, very few errors are made in term of pointing to approximately the correct location. That these differences according to trial types still exist despite scaling down the equipment is in direct opposition to the findings of Somerville and Bryant (1985) who found that there was no effect of absolute distance from the pointer in their small scale pen and paper task. Somerville & Bryant (1985) gave their participants an interpretation task which required them to select which of four dots two markers were pointing to within a square 9cm x 9cm in dimension. It may be that the distances need to be reduced beyond those in this experiment for the effect of trial type to disappear. Additionally the interpretation task in this experiment demands more from the participants, as they need to locate the point rather than select from pre-existing marked locations. The differences according to trial type are not in themselves surprising as there are still relative differences in distance from the markers between trial types.

The results from this study reveal a difference in performance between construction and interpretation tasks, with performance on the construction task being superior to that on the interpretation task. This finding is consistent with the findings of Lidster & Bremner (1999), Lidster (2002) in addition to those of Studies Two and Four. This difference in performance between the tasks was yet again most marked in the Far-Far trials. However, scores on Near-Near trials differed little between construction and interpretation conditions when assessed according to the correct quadrant condition, scores on both tasks for Near-Near trials were close to ceiling. This may however be due to the fact that responses would be classified as correct in this type of trial if the child had done no more than place the cup next to one of the pointers.
No age effects were found in this study according to either scoring criterion. This is surprising in view of the consistent age effects present in the previous studies in this series as well as those found in the studies of Lidster (2000, 2002) and other studies involving children’s spatial abilities (Somerville & Bryant, 1985; Bryant & Somerville, 1986). One possible explanation for this lack of an age effect may be that the cut-off point for allocation to the younger and older age groups was slightly higher in this study. It may be that, because the sample is older than that in the previous studies, age differences are not so apparent. An alternative explanation may be that the scale of the equipment may be a pertinent factor affecting younger children’s performance (Huttenlocher et al., 1994) and that they are capable of performing at the same level as older children when the size of the equipment is reduced. Further research using small-scale tasks would clarify whether this is indeed the case. It is possible that there is a limit to the distance over which younger children can successfully extrapolate lines.

Comparison of the results of Studies Four and Five shows no overall difference in levels of performance due to scaling the equipment down. Scaling down has no simple effect upon performance and children show the same degree of accurate responding even though the target area is also scaled down, lending support to Huttenlocher et al.’s (1994) conjecture that even young children are able to subdivide space ‘where the scale of the bounded space is small’ (page 144) although they give no objective definition of this term. This finding, taken in conjunction with the lack of age effects present in the scaled down task, even when assessed according to the absolute accuracy criterion, supports their finding that although subdivision of large scale spaces such as their sandbox was not present until the age of six, four to five year olds are able to subdivide smaller areas of space to the same degree as older children.

Although there was no overall difference in levels of performance between Studies Four and Five, an interaction between Study and Trial Type according to the absolute accuracy criteria revealed that performance on Far-Far trials and Far-Near trials was superior on the scaled down version compared to the larger version of the task. This suggests that distance from the pointer may be a factor in explaining poorer performance on these tasks in previous studies. Somerville & Bryant (1985) found that there was a significant main effect of distance from the vertical pointer in Study One, using equipment measuring 39cm x 39cm but no effect of vertical distance using
a pen and paper task where the square measured 9cm x 9cm. It may be that the
difference in scores between Studies Four and Five on Far-Far and Far-Near tasks,
which both involve targets that are further from the vertical marker, in this analysis
may reflect the importance of distance from the vertical marker as a factor in
children’s ability to extrapolate lines of projection.

Although a reduction in scale had no overall effect on performance on
construction and interpretation tasks, it does seem to have the effect of reducing the
differences between older and younger children in the performance of these tasks.
Although differences in trial types persist when equipment size is reduced, this may
be because relative differences in distance from the markers are still present. One
effect of the reduction of equipment size may be that performance on trials which
require the extrapolation of lines from the vertical marker is improved. Difficulties in
extrapolating these lines may occur over greater distances because the child is not
able, in these circumstances, to place themselves at a point in line with the marker. In
practical terms the findings suggest that young children’s performance on coordinate
tasks will be optimal where they are presented with materials which do not require
them to extrapolate lines over larger distances.
Chapter 7: Study Six
Young children’s ability to use spatial coordinates on a touch screen

Introduction

The results from the studies of Lidster & Bremner (1999), Lidster (2000) and Lidster (2002) suggest that there is an advantage in construction tasks over interpretation tasks when dealing with children’s ability to use coordinate dimensions. Results from Lidster & Bremner (1999) and Studies One to Three suggest that a large part of this difference may be due to difficulties in performance on Far-Far trials in the interpretation condition. Differences in performance between interpretation and construction tasks were not apparent when responses were classified according to the absolute accuracy criterion. Studies Four and Five used a simplified task with the absence of multiple targets, which it was felt, might lead to biases in responding or interfere in the children’s correct execution of the task. However the attempt to simplify the task appeared, paradoxically, to make the task even harder to complete in the interpretation condition. The requirement to identify the point at which the lines of projection intersected with one another was more difficult than asking the children to select at which of four cups these lines intersected. This effect was more than a simple case of differences in accuracy that could be explained in terms of lack of perceptual support.

Of particular interest are the types of errors made in these studies. Although one aim was to reduce errors children made by selecting a cup nearest to one of the pointers, several children used a strategy of placing the cup directly next to one of the pointers. In addition some children made errors that appeared to consist of placing the cup at a point approximately equidistant from both markers on a line connecting the points of these markers. The construction task could be relatively easier than the interpretation task because it can involve two simple line-of-sight tasks carried out simultaneously rather than requiring the child to coordinate dimensions.

Performance on interpretation tasks suggests that children are often not using an orthogonal/Euclidean system in these tasks. Responses often indicate that children are not projecting lines from the pointers as perpendicular to the axis and prefer to use...
them as points of triangulation equidistant from the target. In both tasks the pointers are rigidly placed on a sliding mechanism such that they always point in a perpendicular direction from the axis. It may be that by requiring the child to line this up with the target in either serial or sequential fashion we are increasing the likelihood of success in the construction task and overestimating their ability to construct rather than interpret coordinate dimensions. The response modalities for the construction and interpretation tasks are very different and this may, at least in part, explain the differences in performance between the two tasks. The primary aim of the present experiment is to see what effect changing the mode of response would have on children’s performance. It is predicted that despite being shown how to complete the task using the Euclidean coordinate system, children, and in particular younger children will have a tendency to complete the task in a non-Euclidean fashion, preferring some other method of indicating location such as triangulation or giving proximal cues.

**Spatial coding**

In terms of locating an object or point in space, children and adults may rely on either cue learning or place learning. Cue learning is an association between a particular landmark and the object/location whereas place learning is locating the object or point in terms of distance and direction from a landmark. This place learning is assumed by Piaget (Piaget & Inhelder, 1956) to be based on a Euclidean concept of space and this notion is pervasive in formalised methods of place location such as maps. However, evidence of distortions and asymmetries in real life and large-scale settings indicate that adult representations of space are partially non-Euclidean (Newcombe & Huttenlocher, 2000). Huttenlocher, Newcombe & Sandberg (1991) suggest that when locating a point within a circle, adults use both fine grained and categorical spatial information to locate a point from memory and encode location along the dimensions of radial distance from the centre of the circle and angle rather than metric distance along two orthogonal dimensions. Further research by Sandberg, Huttenlocher & Newcombe (1996) found that children as young as five years old were able to code location according to these two dimensions but that they did not show angular categorical prototypes, as displayed by bias towards the centre of a segment of the circle, until nine years of age.
Although these studies differ both in materials and in task demands from the current study in that they do not demand the placement of pointers to a particular location but the memory of a location, they raise the issue of what form of spatial coding of a point is predominant. The types of errors displayed by the children in Sandberg et al.'s studies lead them to conclude that the children were not using a Euclidean, orthogonally based system of representation in this setting, but a system of encoding based on distance from the centre and angles. This system of location coding would appear most appropriate to circular environments with limited landmarks. Previous research on young children’s ability to construct coordinates has been carried out under very constrained conditions. Not only have the materials consisted of square or rectangular surfaces, but in most situations some sort of grid system or rigidly placed markers have been imposed upon the experimental situation. It is possible that children’s tendencies and abilities to use orthogonally placed markers to indicate the location of a point within a bounded space have been overestimated due to these constraints and that, left to their own devices children’s use of a Euclidean coordinate system is not prevalent. Results from Studies Four and Five in this thesis suggest that in an interpretation task where they are given free choice as to where to place the cup, children frequently interpret the markers in a non-Cartesian fashion and it may be that where they are not constrained by rigidly placed markers, children will adopt an alternative strategy to indicate the location of a point in space in a construction task.

The use of computer touch screens

Since their introduction as a tool for psychological research in the 1980’s computer touch screens have been used in a variety of settings including research into visual learning in rats (Easton, 2004), concept discrimination in chimpanzees (Vonk & MacDonald, 2004), visual attention in both normal (Gerhardstein & Rovee-Collier, 2002) and atypical children (Huguenin, 1997, 2004; Scerif, Cornish, Driver & Karmiloff-Smith, 2004) and studies involving the perpendicular bias (Commerford, 2004). Research has indicated that in simple tasks such as cursor movement, performance by children on touch screens is comparable to that of adults, whereas young children found greater difficulty in using a mouse or keyboard arrows compared to adults (Scaife & Bond, 1991). Ostroff & Shneiderman (1988) suggest that in adults, touch screen devices, although fastest and most preferred for selecting
highlighted words in a text, have also been shown to be least accurate when compared to other selection devices such as keyboard keys and a mouse. However, Romeo, Edwards, McNamara, Walker & Ziguras’s (2003) study of input devices in early educational settings suggests that children have difficult with operations such as ‘drag-and-drop’ using the touch screen and that perceptual-motor development, familiarity with the mouse and the fact that many educational programmes are designed for use with a mouse may mean it is a more appropriate method of interfacing with the computer than touch screens. In addition they report that the location of the touch screen is important. Several teachers in the study by Romeo et al. (2003) report that children are put off using the touch screen by having to reach up to it, thus touch screen position and placement may be an issue in this study.

Despite limitations in some settings, touch screens are useful tools for obtaining data from young children. Gerhardstein & Rovee-Collier (2002) used a touch screen-embedded game to elicit visual search reaction time data from children between twelve and thirty-six months, such data have been difficult to obtain using standard techniques and verbal instructions in young children. Commerford (2004) found that use of a computer touch screen enabled her to gain precise data concerning the accuracy and errors in children’s responses in line drawing and ‘click at end’ tasks when studying the perpendicular error in children’s drawings, the use of computer touch screens allows precise information about the exact location and timing of responses to be recorded and so in situations in which pointing to a location or object upon the screen are required, they can provide a wealth of information. As the use of two scoring criteria in this thesis reveals accuracy of response to be an important consideration, the touch screen will be a valuable aid as it permits children to respond to both interpretation and construction tasks by means of a pointing response and records these responses with a much greater degree of accuracy. The main advantage however is that it allows children to use similar response modes in both interpretation and construction tasks and that responses are not constrained by the nature of the equipment as in previous studies.

Aims of the study

The aims of this study were twofold. Firstly, the study aimed to compare performance on interpretation and construction tasks where the method of responding was the same in both tasks. It was felt that the demands of the interpretation task in
previous studies might have exceeded those of the construction task due to the
differences in responding and the fact that the pointers could only be perpendicular to
the axis so being less likely to lead to errors. Secondly, the study aimed to investigate
whether children were likely to exhibit the same types of errors in the construction
task as those displayed in the earlier interpretation tasks if they had more freedom in
choosing the location of the pointers. One possibility is that, despite the presence of
orthogonally placed axes, children may cue location in the construction task using
topological or projective cues.

Method

Participants

Twenty children between three years ten months and five years nine months
took part in this study (mean age five years). There were thirteen males and 7 females.
The children were taken from a local nursery school and the reception class of a local
primary school. Both were in a predominantly white, middle class area of Surrey.
Children were divided into two age groups on the basis of whether they were above or
below the mean age of five years (mean age for the younger group 4 years 7 months,
n=10, range = 3 years 10 months –5 years; mean age for the older group 5 years 5
months, n =10, range = 5 years ½ month – 5 years 9 months). None of the children
had participated in the previous experiments.

Materials

The task was presented to the children by means of a 15-inch diagonal touch
sensitive LCD screen (Elo Intellitouch). The stimuli were scaled-down so that the
proportions were identical to those in Experiments One to five and consisted of an
18cm x 18cm grey square with a darker grey border which was centrally displayed on
the touch screen. Four black circles of 1.8cm diameter were displayed within this
square, each circle having its centre approximately 4.5 cm from two adjacent sides
(see Figure 7.1). The touch screen was controlled by an Apple Powerbook G4 which
had been programmed using MatLab (Mac v. 5.2.1). The program had been written to
reward the children by the reappearance of the cross when they selected the correct
circle in the interpretation task and also when they placed their fingers in the correct
position along the axes to point to the cup. As positioning of the touch screen has
been found to be an issue in other studies related to touch screen use (Romeo et al., 2003), the touch screen was placed on a horizontal surface in front of the child so that they were able to look down onto it.

Figure 7.1. Touch screen showing interpretation trial

Design

Experiment Six consisted of three tasks: an interpretation task, a serial construction task and a simultaneous construction task. Each child received eight trials in each task, a total of twenty-four trials overall. Once again a multivariate design was used to allow for the effects of more than one independent variable to be assessed. As in all previous experiments a between-participants independent variable of Age was included, having two levels, above or below five years old. In addition the design included within-participant independent variable of Trial Type and Task. As in previous studies there were four levels of trial type which related to the position of the target relative to the pointers and there were three levels of task; an interpretation task, a simultaneous construction task and a serial construction task. All children completed all tasks, which were presented in random order. This allowed us to combine elements from Experiment One (serial vs. sequential construction) and Experiments Four and Five (Interpretation vs. Construction). In the interpretation
task, as in Studies Four and Five, markers appeared along two adjacent sides of the square, pointing at the centre of one of the four circles and the child was required to indicate which circle by touching that circle on the touch screen. In the construction task a cross appeared on one of the circles and the child was required to place fingers along two adjacent edges of the square to point to the circle where the cross had appeared. This method of response differed from all previous construction conditions as the children, although instructed to place fingers orthogonally on the axes, had greater freedom regarding positioning of location cues than in previous studies in this thesis. The dependent variable for the interpretation task was the number of correctly identified target as in previous interpretation tasks and the dependent variable for the construction tasks was the number of responses indicating the correct circle scored using the same criteria as previous construction studies.

**Procedure**

Each child was tested in a quiet corner of a classroom. Before the task they were asked if they would like to play a game. The experimenter explained that it was a pointing game.

In the serial construction task the child was told that a cross was going to appear on one of the circles on the screen and that when it disappeared the experimenter wanted them to show where along the edges they would put a pointer to show where the cross was. During the explanation the experimenter indicated the edges where the pointer would be placed. The experimenter then demonstrated with the following words: ‘Look, I’ll show you how’ (Far-Far example appears) ‘I’m going to point here and here’ (places fingers in line with correct circle) ‘so that if you draw a line from each finger, where the lines meet is where the cross is...look there it is!). The child was then given an opportunity to practice using a Near-Far and a Far-Near trial.

In the simultaneous construction task the explanation was the same but it was stressed that they should put their fingers down ‘both at the same time’. For the interpretation condition the child was told that their aim was to find the circle hidden on one of the crosses. The experimenter explained that the two red pointers on the edges of the square were pointing to the circle with the cross and that if the child drew a line from both pointers, where the lines met was the right circle. The experimenter

148
demonstrated this with a Far-Far trial and then the child was allowed two practice trials, one Near-Far and one Far-Near.

The child was given eight trials in each task, corresponding to one of each trial type with the axes in the bottom-left and top-right position. In the construction task the order of presentation was completely randomised. However, results of a pilot study suggested that continually changing which axes the children had to place their fingers on might lead to confusion in the construction task and so all the trials using the bottom-left axis were presented in a block followed by all the trials with the top-right axis. The order of the tasks was randomised.

**Figure 7.2** Position of touch screen and Notepad relative to child.

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**Results**

The participants’ responses were recorded by the computer in terms of position indicated on the touch screen. The central point indicated by the finger used to touch the screen was recorded in terms of pixel location. In the interpretation task one point was recorded and in the case of the construction task two points were recorded, one for each finger and also the time delay in milliseconds between the two recordings.
Interpretation task

Distances from the target location represented by the central pixel of the correct cup were recorded. Responses were then coded as being correct on the basis of whether the location indicated by the child fell within the area of the correct circle.

Construction Task

The program was designed to record two separate sets of coordinates, one for each finger. However on examination of results recorded from the serial and simultaneous conditions it was noted that in some instances the coordinates of the two points recorded were identical. This was felt to be the result of some anomaly in responding and so these data were discarded and analysis was carried out only on the data where two distinct coordinates had been recorded. Approximately 5% (8 responses) of the data from the serial condition and 10% (17 responses) of the data from the simultaneous condition were discarded.

Results from the Interpretation Task

Initial analysis of the results suggests that children often did not indicate the correct circle by placing a finger inside the circle. This may have been the result of the experimenter not stressing the importance of touching the circle to indicate the correct answer, however the majority of children were able to clearly indicate which of the circles was indicated by the marker. The children had two trials for each trial type. As the children had fewer trials in this study than in previous studies, a direct comparison of numbers of correct responses for each trial type was not appropriate therefore the percentages of children scoring correctly on both of the trials were recorded as follows (number in brackets):

<table>
<thead>
<tr>
<th>Trial type</th>
<th>Near-Near</th>
<th>Near-Far</th>
<th>Far-Near</th>
<th>Far-Far</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger children</td>
<td>100 (10)</td>
<td>30 (3)</td>
<td>40 (4)</td>
<td>20 (2)</td>
</tr>
<tr>
<td>Older children</td>
<td>60 (6)</td>
<td>60 (6)</td>
<td>80 (8)</td>
<td>40 (4)</td>
</tr>
<tr>
<td>Combined</td>
<td>80 (16)</td>
<td>45 (9)</td>
<td>60 (12)</td>
<td>30 (6)</td>
</tr>
</tbody>
</table>
These results compare favourably with those scoring correctly on all trials of the standard interpretation task in Study Two (76%, 57%, 62%, 52% for older children and 38%, 19%, 27% and 0% for younger children). In particular the performance of the younger children appears to have been facilitated by the use of a touch screen. It is possible that having to complete fewer trials lessens the possibility of responding incorrectly on one of the trials.

Comparison of the percentages of correct responses on each trial type for the standard and the touch screen task is given below.

Table 7.2. Percentage of correct responses on an interpretation task, for each trial type under touch screen and standard conditions (in brackets)

<table>
<thead>
<tr>
<th>Trial type</th>
<th>N/N</th>
<th>N/F</th>
<th>F/N</th>
<th>F/F</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Older children</td>
<td>70 (93)</td>
<td>70(87)</td>
<td>85(87)</td>
<td>60(74)</td>
<td>71.25(86)</td>
</tr>
<tr>
<td>Younger children</td>
<td>100(75)</td>
<td>60(57)</td>
<td>60(63)</td>
<td>25(33)</td>
<td>61.25(57)</td>
</tr>
<tr>
<td>Combined</td>
<td>85 (84)</td>
<td>65(72)</td>
<td>72.5(75)</td>
<td>42.5(53.5)</td>
<td>66.25(71)</td>
</tr>
</tbody>
</table>

Mean numbers of correct responses for each trial type were analysed using a two factor Trial Type (4) x Age (2) ANOVA on the touch screen data, with repeated measures on the first factor. This revealed a main effect for Trial Type (F (3,54)= 8.37, p<0.001) and a significant Trial Type x Age interaction (F (3,54)=5.35, p<0.005) but no Age effect F (1,18)=0.662, p>0.05). This interaction appears to be typified by young children scoring at ceiling on the Near-Near trials and very poorly on the Far-Far trials (see Figure 7.3).

Because of differences in the number of trials completed in Study Two and the present study, one trial of each type was randomly selected from each of the participants in Study Two and compared with performance on a randomly selected trial from the two trials in the present study.

Data were analysed by means of a three-factor Trial Type (4) x Age (2) x Study (2) ANOVA with repeated measures on the first factor. This revealed significant main effects for Trial Type (F (3,174) = 11.623, p<0.001) and Age (F (1,58) =6.329, p<0.05) but not for Study (F (1,58) =0.198, p>0.05). Performance was
superior on Near-Near trials and poorest on Far-Far trials. Older participants scored more correct responses than younger ones overall (see Figure 7.4).

In addition to the above main effects, significant Age x Trial Type (F (3,174) = 3.80, p<0.05) and Age x Study (F (1, 58) =4.74, p<0.05) interactions were found. Examination of these interactions suggests that older children performed better than younger ones in all trial types except Near-Near trials. Figure 7.5 indicates that the Age x Study interaction is a result of younger children performing better overall on the touch screen experiment compared to the standard experiment whereas the opposite is the case for older children.

Figure 7.3: Mean number of correct responses (out of 2) on interpretation task by trial type and age.
Figure 7.4 Mean scores (out of 1) for randomly selected interpretation trials from Studies 2 and 6 by trial type and age.

![Mean scores](image)

Age
- <4 years 11 months (n=31)
- 4 years 11 months (n=31)

Trial Type

<table>
<thead>
<tr>
<th>Trial Type</th>
<th>Mean number of correct responses (out of 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>near-near</td>
<td>1.0</td>
</tr>
<tr>
<td>near-far</td>
<td>0.8</td>
</tr>
<tr>
<td>far-near</td>
<td>0.6</td>
</tr>
<tr>
<td>far-far</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Figure 7.5 Mean total scores for older and younger children (out of 4) in Studies 2 and 6 (Standard vs. touch screen tasks)

![Mean total scores](image)

- Study 2
- Study 6

Mean number correct responses (out of 4)

<table>
<thead>
<tr>
<th>Age</th>
<th>Mean number correct responses (out of 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>younger</td>
<td>2.5</td>
</tr>
<tr>
<td>older</td>
<td>3.5</td>
</tr>
</tbody>
</table>

153
Results from the construction task

Analysis of the results from the construction task proved somewhat more problematic than those from the interpretation task. What was most remarkable was that despite repeated instructions on each trial to place one finger on the x axis (either top or bottom) and one on the y axis (either left or right), few children were able to complete this task as intended by the experimenter.

Children’s responses were classified according to six categories:
1) Both fingers are placed close together within the area of the square.
2) Both fingers were placed along one of the axes.
3) Both fingers were placed close together along one of the axis
4) One finger was placed on each of two perpendicular axes.
5) One finger was placed on each of two parallel axes
6) One finger was placed along one axis and the other was inside the square or both were inside the square but not close together.

Of these categories only category 4 includes responses that were deemed to be correct. In both the simultaneous and serial construction tasks roughly 1/3 of the responses involved use of both the appropriate axes. Table 7.3 shows percentage of different types of response in both simultaneous and serial construction tasks.

Analysis of the construction responses where two axes are used suggests that even though children are using two orthogonally located axes, they are not using it in a Euclidean fashion. Very few of the responses line up with the target when lines perpendicular to the axis are drawn (41% of those in the simultaneous condition and 33% of those in the sequential condition). Because so few responses used two orthogonally placed axes further analysis of this data according to trial type was not possible. Comparison of data from the construction and interpretation tasks was also not possible.

The other most common method of indicating the location was by placing two fingers close together on a single axis. These responses usually consisted of placing the fingers at a point on the axis near to the target although not in all cases.
Table 7.3: Frequency (Percentages in brackets) of different response types in serial and simultaneous conditions of construction task

<table>
<thead>
<tr>
<th>Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simultaneous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger children</td>
<td>4</td>
<td>7</td>
<td>22</td>
<td>23</td>
<td>3</td>
<td>10</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(10)</td>
<td>(32)</td>
<td>(33)</td>
<td>(4)</td>
<td>(15)</td>
<td></td>
</tr>
<tr>
<td>Older children</td>
<td>2</td>
<td>13</td>
<td>18</td>
<td>28</td>
<td>5</td>
<td>8</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(18)</td>
<td>(24)</td>
<td>(38)</td>
<td>(7)</td>
<td>(11)</td>
<td></td>
</tr>
<tr>
<td>Serial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger children</td>
<td>2</td>
<td>14</td>
<td>31</td>
<td>24</td>
<td>5</td>
<td>3</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(18)</td>
<td>(40)</td>
<td>(31)</td>
<td>(6)</td>
<td>(6)</td>
<td></td>
</tr>
<tr>
<td>Older children</td>
<td>2</td>
<td>4</td>
<td>28</td>
<td>21</td>
<td>9</td>
<td>9</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(5)</td>
<td>(38)</td>
<td>(29)</td>
<td>(12)</td>
<td>(12)</td>
<td></td>
</tr>
</tbody>
</table>

1=Both fingers are placed close together within the area of the square. 2=Both fingers were placed along one of the axes. 3=Both fingers were placed close together along one of the axes. 4=One finger was placed on each of 2 perpendicular axes. 5=One finger was placed on each of 2 parallel axes. 6=One finger was placed along one axis and the other was inside the square or both were inside the square but not close together.

Discussion

Results of the interpretation suggest that overall levels of performance are similar to those in the standard task since there was no main effect of Study found in the analysis. However closer inspection of results for younger and older children over the different trial types suggest that younger children's performance on the touch screen is at ceiling in Near-Near trials and that levels of performance on Far-Far trials may be poorer amongst younger children than older children when using the touch screen in comparison to the standard task. These results however must be interpreted cautiously due to the small numbers in each of the groups; the responses of very few children can have a large effect on overall results, especially when the numbers of trials per child is also reduced.
Results from the construction task are particularly interesting as they suggest that children do not use a single strategy for indicating location. No child showed a consistent method of pointing to the location across all trials although some children did show a predominance of certain responses. This finding is consistent with Siegler’s (1996) ‘overlapping waves’ theory which suggests that children have a variety of strategies available to them for problem-solving and also supports Newcombe & Huttenlocher’s (2000) claim that children have multiple spatial coding strategies available to them.

However, there seems to be no association between age and use of Euclidean coordinates in the construction task. Indeed, there appears to be no preference for a Euclidean coordinate system within either of the age groups, with this being one of the least used strategies. Only 21/143 responses in the simultaneous task and 15/152 responses in the sequential condition showed accurate use of a Euclidean coordinate system. These results lend support to the view of Piaget & Inhelder (1961) that children are not capable of using a Euclidean coordinate system until the age of around eight or nine years.

Children in the construction task most commonly angled their fingers along the axis to point towards the target. The second most common strategy overall and the commonest in the sequential condition is to use two fingers close together on a single axis. Here the children also angled their fingers to point at the target although many placed their fingers level with the target on the axis. There is no way of gauging, with the present data recording system, how accurate children are when using this or any other method. However, studies of children’s pointing in large scale spaces suggest that children are often more accurate at indicating locations by pointing with their fingers in comparison to other forms of rotating pointers (Lehmung et al., 2001).

Results from this experiment have strong implications for earlier research and suggest that many of the findings of previous research into construction and interpretation of coordinate dimensions may overestimate children’s abilities (Lidster & Bremner, 1999; Lidster, 2002). Studies Four and Five indicated that children’s performance levels on interpretation tasks are vastly reduced in the absence of fixed choices of location and this may be due to the absence of perceptual support in these tasks. Performance in Studies 4 and 5 indicates that without possible choice locations placed in a grid like pattern, children frequently interpret the location cues in a non-Euclidean fashion and responses support the idea that young children’s notion of
spatial coding is bound up in concepts of proximity and projection (Piaget & Inhelder, 1961). These findings are also apparent in this study; children often optimised proximity to the target when they were not constrained by orthogonally placed pointers, by placing both fingers near to or along the axis nearest to the target. This suggests that children may view proximal cues as the most appropriate cue to location. In addition children also occasionally placed their fingers on two parallel sides of the square so that the target lay on a line between these two points. This suggests that children are also using lines of projection along a single dimension as cues to location.

Another possibility suggested by these findings is that children prefer a system of triangulation to code location rather than a Euclidean system. Research by Newcombe and colleagues (Huttenlocher, Hedges & Duncan, 1991; Sandberg, Huttenlocher & Newcombe, 1996) suggests that both adults and children code location according to a polar system of coordinates. Biases in location memory suggest that information is frequently categorised in terms of angle and radial distance from a point. Sandberg, Huttenlocher & Newcombe (1996) suggest that young children are able to code both distance and direction at an early age but that young children are not capable of hierarchical coding along both dimensions simultaneously. Triangulation is a method of place location that places no requirement upon the child for measurement of distance. Provided the child has accurate angular information from two cues then locations can be uniquely specified. This is also true for Euclidean coordinate systems. However the critical difference is that the Euclidean system requires some form of rectangular structure to be imposed upon space.

Earlier studies have used orthogonally placed axes and arrows or similar pointers and children show reasonably high levels of competence on construction tasks using these methods however their responses are very much constrained by these items. The Euclidean nature of the task is evident from the equipment. On construction tasks they can be solved using a line-of-sight technique. Although no difference was found in our studies between serial and sequential tasks it is possible that children are able to complete this task as two separate line-of-sight tasks carried out in parallel. This represents an important empirical question for future research.
Chapter 8: General Discussion

Overview

Chapter 8 begins by summarising the results of Studies 1-6 and discussing their contribution to understanding of children's spatial abilities and the development of these abilities. A theoretical account of these findings and suggestions for the direction of future research are also given.

Summary of Results

The aims of Study One were to investigate construction versus interpretation effect as found in the work of Lidster & Bremner (1999) but absent from that of Blades & Spencer (1989) and to explore whether this effect could be accounted for by the sequential nature of the construction task in Lidster & Bremner's study. Also of interest was the extent to which the degree of precision required in the construction task affected performance on this task. In addition the study aimed to look for developmental trends in the ability to construct coordinate dimensions and to investigate types and sources of error in young children's performance on construction of coordinate dimensions.

As in previous studies (Blades & Spencer, 1989; Lidster & Bremner, 1999; Lidster, 2002) there was evidence of early ability to construct coordinate dimensions—the vast majority of children scored above chance level. However there was no evidence of a difference in levels of performance between simultaneous and sequential condition which at first glance suggests that the difference between interpretation and construction tasks found by Lidster & Bremner (1999) was not due to the serial nature of the construction task enabling the children are to complete the construction task without the necessity to coordinate dimensions. However there still remains the possibility that children are completing two separate line-of-sight tasks in parallel.

Study One revealed an improvement in accuracy with age. This is consistent with other studies of spatial tasks (Lidster, 2002). Siegel & White (1975) report consistent age related improvements in spatial abilities in large-scale environments and Huttenlocher, Newcombe and Sandberg (1994) suggest that variability in responses on spatial memory tasks decreases with age as a result of increasing hierarchical coding. However, the improvement in accuracy with age on this task which is unrelated to spatial memory suggests that this reduction in variability may
not be related to increased hierarchical coding alone but that there are age-related improvements in the ability for fine-grained coding of location supporting Huttenlocher et al.'s (1994) additional suggestion that young children show subdivision of small areas of space.

Study One also revealed substantial differences in the levels of performance when assessed using two different criteria suggesting that Lidster & Bremner’s (1999) results may have been influenced by a degree of imprecision in measurement. By accepting a response as correct when the child merely indicated a location within the correct quadrant rather than a point in space occupied by the cup, Lidster & Bremner (1999) may have overestimated young children’s ability to accurately construct coordinate dimensions. The presence of a trial type effect consistent with previous research (Lidster & Bremner, 1999; Lidster, 2002) was also noted although performance according to one criterion on Far-Far trials was improved in the simultaneous condition, most probably as a result of bi-manual coupling (Kelso, Southard & Goodman, 1979) whereby the movement of both hands is temporally linked and thus move to approximately the same degree along the two axes, resulting in the correct quadrant being indicated.

The majority of errors in Study One consisted of errors on a single dimension, suggesting that children are able to use accurate location coding on one dimension but not both. These findings are consistent with those of Blades & Spencer (1989) who found that children in interpretation tasks frequently selected locations in line with one or other of the markers. Piaget & Inhelder (1967) suggest that in mental rotation tasks children are unable to mentally manipulate more than one dimension at a time because of their lack of Euclidean coordinate system. Similarly Sandberg and colleagues (Sandberg, 1995; Sandberg et al. 1996) suggest that categorical coding may occur along only one dimension in young children.

Study Two involved children interpreting coordinate dimensions by asking them to identify which of four upturned cups was the hiding location of a card teddy on the basis of orthogonally placed cues to location and aimed to determine whether the developmental differences present in the construction condition were present in the interpretation condition. In addition this study aimed to look at the effect of the more stringent method of scoring construction responses on the interpretation/construction effect by comparing the results of Study One and Study Two.
Results of this study were consistent with those of Lidster & Bremner (1999) with approximately half of the children scoring at levels above chance. The age effects present in Study One were also evident as were Trial Type effects as found in previous studies (Bremner, Andreasen, Kendall & Adams, 1993; Lidster, 2002; Lidster & Bremner, 1999). Of particular note was the finding that overall differences in performance between construction and interpretation tasks were only evident if scores were compared using the less stringent scoring system for the construction tasks. This may in part explain the difference in results between Lidster & Bremner's (1999) study and that of Blades & Spencer (1989) as the latter consisted of a greater number of possible locations and a greater degree of accuracy may have been needed. Although there was no overall difference between construction and interpretation tasks, Far-Far trials were much harder on the interpretation task than the construction task but performance improved with age.

Study Three aimed to investigate the reasons behind children's poor performance on far/far interpretation trials and in particular the possible 'masking effect' of objects between the location markers and the target in interpretation tasks. This was manipulated by using two- and three-dimensional materials in an interpretation task with a greater number of location choices. Even with increased numbers of possible locations the number of children scoring above chance levels was 70% reinforcing previous findings that young children are able to interpret coordinate dimensions (Blades & Spencer, 1989; Bremner et al., 1993; Lidster & Bremner, 1999; Lidster, 2002). Contrary to previous findings by Lidster (2002) there was no difference due to the dimensionality of the materials. This suggests that the superiority in Bremner et al.'s (1993) study of line-of-sight and line-of-walk tasks compared to the basic task is not due to the marker protruding above the height of objects on the board. A comparison of the results of Studies One and Three suggests that the construction versus interpretation effect is only evident when a comparison of performance between the sequential construction task and the interpretation task is made using a less stringent scoring criterion. These are exactly the conditions under which Lidster & Bremner (1999) report this difference.

In this study a large majority of errors were in line with one or other of the pointers suggesting children are only taking information from one of the dimensional markers into account. Only twenty percent of the wrong choices involved selection of a location next to one or other of the markers, supporting Bremner et al.'s (1993)
finding that relatively few errors involve ‘next to pointer’ selection. Older children’s errors were found to be sensitive to dimensionality. Although older children made fewer errors than younger children, the amount of errors not in line with either of the pointers decreased significantly in the two-dimensional condition relative to the three-dimensional condition suggesting that in the older children the extrapolation of lines from the pointer is aided using two-dimensional materials.

Studies Four and Five aimed to investigate the reason for poorer performance on far/far trials that was most strongly evident in interpretation tasks. This was done by presenting a single target in the construction task to eliminate the effect that the presence of other objects, and by requiring the children to place an object at a location in the interpretation task. Study Five reduced the scale of the equipment to one quarter of the size of that used in Study Four to evaluate the effects of the distance of extrapolation from the marker on performance. Performance on the interpretation under the single target condition was much poorer than that in the construction condition and this suggests that degree of perceptual support may be an important factor in performance on interpretation tasks as found by Lidster (2000).

Error analysis suggests that the children may use the location markers as proximal or projective cues to location rather than in a Euclidean fashion supporting Piaget & Inhelder’s (1956) contention that children are unable to use a Euclidean coding system until later childhood. Study Five revealed that differences in performance between trial types persist despite scaling down the equipment and so reducing the distance of extrapolation from the marker. These trial type effects occur predominantly in the interpretation trials. Although these findings of trial type effects coincide with those found in previous studies using 50cm x 50 cm boards (Lidster, 2002; Lidster & Bremner, 1999) they are at odds with the findings of Somerville & Bryant (1985) who found no effect of absolute distance from pointer in their small-scale pen and paper task.

Two findings regarding the use of scaled down equipment support Huttenlocher et al.’s (1994) findings that young children may show subdivision of space ‘where the scale of the bounded space is small’ although there is no objective definition of this term. Firstly there is no difference in overall levels of performance, when assessed according to a strict criterion of accuracy, between the large-scale and the small-scale equipment. This suggests that as the scale of the equipment is reduced, that space becomes subdivided further than in the larger area. Secondly, when the
scale of the equipment is reduced the differences in performance between the younger children and the older children are not apparent although this finding must be treated with caution as the cut off point between the younger and older children is slightly higher for Study Five. Performance on the scaled-down version did lead to improvements in Far-Far and Near-Near trials. This supports the findings of Somerville & Bryant (1985, Study One) who found that distance from the vertical pointer was a factor in their larger scale task but not in a smaller scale pen and paper task.

The aim of Study Six was to compare performance on construction and interpretation where both methods of responding are the same and responding on construction tasks is not constrained by the presence of markers perpendicularly attached to the axis. It was thought, on the basis of errors in the previous studies that children might show different patterns of response than previously.

Results of Study Six revealed similar levels of correct responses on the interpretation task as in the standard interpretation task, the patterns or errors yet again suggesting that children are capable of interpreting one dimension correctly. However in contrast to other studies (Blades & Spencer, 1989; Lidster & Bremner, 1999) children showed very poor levels of performance on the construction task, in Euclidean terms, with only approximately one third of trials being completed as intended by the experimenter. This finding is very important as it suggests that the constraints imposed upon children by previous research may have affected the conclusions drawn regarding their ability to complete construction tasks. In particular previous research may have overestimated young children’s ability to construct spatial coordinates.

In contrast to the conclusions from previous research, children in Study Six used a variety of techniques to indicate location and these varied from trial to trial. These results suggest that none of the children was able to readily grasp the concept of orthogonal cues to location and none showed a preference for a Euclidean system of location coding. These findings challenge the recently accepted viewpoint that young children are capable of accurately constructing Euclidean coordinates far in advance of the age proposed by Piaget & Inhelder (1961) (Blades & Spencer, 1989; Lidster, 2002; Lidster & Bremner, 1999). Rather than a Euclidean system, many children chose to place their fingers next to each other along a single axis suggesting a reliance on a projective system which includes angular information, supporting Piaget
& Inhelder’s conjecture that coding of location is non-Euclidean before the age of eight or nine years. This finding also supports Huttenlocher et al. (1994) and Sandberg et al.’s (1996) claim that a system of polar coordinates is frequently used to locate a point in space.

The role of proximal cues in young children’s spatial coding was also emphasised by these results. In the majority of cases children in this study aimed to maximise the proximity of the cue to the target suggesting that topological coding of location is predominant in young children. In addition to both projective and topological coding, there was also some evidence for a system of triangulation to indicate the location of objects, although the results suggest there were no particular preferences in terms of angles or equidistance between cues.

**Factors effecting young children’s use of spatial coordinates**

Taken as a whole the present series of experiments would seem to suggest that young children can construct and interpret orthogonal cues to location at an age much earlier than that proposed by Piaget & Inhelder (1956) and that is certainly the interpretation that previous studies have placed on their data (Blades & Spencer, 1989; Lidster & Bremner, 1999; Lidster, 2000; Somerville & Bryant, 1985; Bremner et al., 1993). Despite possible criticisms levelled at studies using two by two displays that suggest these levels of performance on interpretation tasks could be achieved by selecting on the basis of proximal or projective cues, performance on the six by six display of Study Two shows that the vast majority of children are performing at above chance levels. These results support the findings of Blades & Spencer (1989) suggesting that children between three years and ten months and five years and ten months have some manifestation of abilities which Piaget & Inhelder (1956) propose to emerge at around the age of nine. However although young children appear to be able to interpret and construct Euclidean coordinates and to use them in transfer tasks (Lidster, 2002) it is clear that task factors play an important role.

Perceptual support appears to be an important factor. Although Blades & Spencer (1989) found no difference in performance on construction and interpretation tasks with and without grid lines, Lidster (2002) found that the provision of perceptual support leads to improvements in task performance which persisted at three month follow up and Studies Four, Five and Six in this thesis suggest that where any form of perceptual support is absent then performance is affected. Children in the
interpretation task performed much more poorly when required to freely interpret orthogonal cues to location and children in the construction condition performed very poorly indeed when fixed perpendicular markers were not provided. Some of this may of course be a function of the child's ability to understand the task demands. The effect of perceptual support found in Lidster's study may simply be an effect of having explained the demands of the task in a clearer fashion rather than the result of a greater understanding of the principles of Euclidean coordinate systems since the nature of the materials already provides some degree of perceptual support.

Although there is evidence that children are able to use a system of Euclidean coordinates to locate a point in space, results from this study suggest that this is far from being the predominant system of coding. Success on two by two displays can be achieved in all of the Near-Near interpretation trials by using either proximal or projective cues and in half of Near-Far and Far-Near trials. Successful completion of Far-Far trials is the only situation in such displays which requires coordination of dimensions for success, and success rates in these trials are low compared to those in other trial types (Lidster & Bremner, 1999; Lidster, 2002). Bremner et al. (1993) suggest that scores on their standard interpretation task are a reflection of these probabilities. Consistent trial type effects have been found across all studies, typified by young children having greater difficulty in solving Far-Far trials on interpretation tasks and this is found using both two by two and six by six arrays. The existence of such effects using six by six arrays suggests however that children are not simply solving the task using projective and proximal cues and that other factors such as absolute distance and number of intervening items between pointers and the target may play a role. Projective and proximal cues might lead to equivalent error rates across all trial types if this were the only influencing factor.

Age effects are seen in all but the scaled down versions of the task although it is not clear whether these age effects are due to a limitation of the child's abilities or their motivation or learning/understanding of the task. However the absence of age effects on the scaled-down task might indicate that younger children are more influenced by factors such as the distance of extrapolation of lines. This is consistent with the findings of Somerville & Bryant (1986) who found that older children were less affected by the length of extrapolation than younger children.

Results of the error analysis on interpretation tasks and construction tasks where responses are not tightly constrained seem to be indicative of a preference for
using proximal or topological cues to location. Analysis of error patterns suggests that although children may not accurately identify the correct position of an object, their responses are frequently in line with the pointer on one dimension as found by Blades & Spencer (1989) and may suggest an ability to take one dimension into account but not both simultaneously (Piaget & Inhelder, 1956). However these responses often lie within the correct quadrant of the apparatus and it may be that categorical coding is not operating on both dimensions (Huttenlocher et al., 1994) and so coding along one dimension is not as accurate as that along the other.

The results from the error analysis and from the construction condition of Study Six suggest that young children use more than one method of coding location. Strategies for interpreting the information given by the pointers include choosing a location in line with one of the pointers (projective cue) or choosing a location next to one of the pointers (topological/proximal cue). Evidence from these studies suggests that younger children may be more reliant on proximal cues than older ones and supports Bremner et al.'s (1993) suggestion that these strategies are used only if they are an adequate heuristic. In situations where there is no possibility of success using this strategy then it is not used to same degree. The occurrence of this type of error in the six by six array in Study Three was much less common than in other two by two arrays, suggesting that young children are able to adapt their strategies according to the strategy's value to the task.

The fact that children are capable of using Euclidean coordinates at an early age in some situations but tend as a matter of choice to also use proximal and projective methods for constructing cues to location supports the idea that children have more than one method of coding space available to them (Huttenlocher & Newcombe, 2000; Newcombe, Huttenlocher, Drummey & Wiley, 1998). In this respect the results from Study Three and Study Six are highly important. If only topological or projective cues were available to the child then we would not expect to see as large a percentage of the children scoring at above chance levels in Study Three. A reliance on purely proximal cues typified by the 'search-next-to-pointer' strategy would not lead to success in any of the trial types, whereas a reliance on projective cues in the absence of coordinating two dimensions would give rise to only a one in six probability of success. Nor would we expect to see the variety of responses given in the construction condition of Study Six. Studies of problem-solving in children suggest that there is variability of strategy choice between tasks
and within tasks (Siegler, 2002) and that children may not be consistent in the techniques they use across trials or within trials.

During the construction task children often try to maximise proximal cues, by placing fingers close to the target, using a single line of projection. Studies of young children’s knowledge of distance and direction in large-scale space suggest that children have a reasonably accurate knowledge of distance and direction between points but that distances tend to be overestimated and that smaller distances tend to be overestimated to a greater degree (Downs & Stea, 1977). Anooshian & Kromer (1986) suggest distance and direction estimates are independent of each other and that children who are accurate at distance estimates are not necessarily those who are accurate at estimates of direction.

In the construction trials of Study Six, where fingers were not placed together, then children use points along two axes more commonly than one and most commonly this takes some form of non-Euclidean triangulation. Triangulation can be achieved either through accurately measured distances or accurately measured angles from two points. In many everyday situations triangulation is a highly effective system of location coding requiring no distance information to be coded, only directional information from two points and is highly useful if two fixed landmarks exist. However angular information may be difficult to retain accurately in memory and there is evidence that there is a natural inclination towards the perpendicular which may affect the accuracy of remembered angular information and which is demonstrated by the perpendicular error in children’s drawings.

Research into children’s drawing suggests that whereas children as young as three years old are able to recognise the correct depiction of vertical objects on tilted surfaces (such as chimneys on roofs), a bias exists in their drawings of these objects such that they are drawn more perpendicular to the baseline (Perner, Kohlmann & Ibbotson, 1984). This bias occurs with both abstract and meaningful materials (Ibbotson & Bryant, 1976) and whether the baseline is horizontal, oblique or vertical, although the effect is lessened with vertical baselines (Ibbotson & Bryant, 1976; Davis, Boyles & De Bruyn, 2002).

Bias in children’s drawings and performance on tasks such as the water jug task have been taken by proponents of Piaget to indicate a lack of understanding of Euclidean space, as the meaning of horizontality and verticality only becomes clear once the Euclidean concepts of position along invariant horizontal and vertical axes is
established. However recent research suggests that perpendicular bias may arise as the results of a bisection error. Bremner & Taylor (1982) suggest that perpendicular bias may in fact be due to a bias towards creating two equal angles between the line and the baseline. The existence of this bias is supported by Pigram (1984) who suggests that when children are required to match triangles they often select those which more symmetrical than the correct triangle. The bias towards perpendicularity does not confine itself to children. Sadalla & Montello (1989) found that when adults were asked to give estimates of direction travelled those nearer to 90, 180 and 270 degrees were more accurately estimated and that estimates tended to be nearer these angles than they actually were. Whatever the basis for this perpendicular bias, it may be that in situations where children are required to construct cues to location based on a remembered location then there would be an increased reliance on Euclidean cues, which utilise perpendicularity, rather than projective cues or triangulation.

The studies reported in this thesis suggest that there is significant developmental change in children’s ability to construct and interpret coordinate dimensions between the ages of three and six and that this change includes an increase in the accuracy of children’s use of cues to location. Whether this is the result of a cognitive change in their representation of space or an increased understanding of the need for accuracy is unclear.

Younger children seem to show a greater reliance on non-Euclidean strategies to interpret and construct cues to location although there is substantial evidence both in this study and other studies to suggest they are able to construct and interpret Euclidean coordinates if the conditions are right. This suggests that young children’s spatial understanding includes, proximal, projective and Euclidean concepts and that, whereas children may favour one type of cue to location, they may utilise others in situations in which they are more appropriate or useful. Newcombe & Huttenlocher (2000) suggest that adults and children possess multiple forms of spatial coding including self-referent coding, dead-reckoning and the use of proximal and distal landmarks. Piaget & Inhelder (1956) recognise that even very young children must possess some element of metric and projective coding of space (Page 11). The change in reliance on one cue rather than another may develop through experience of its heuristic value in particular situations.
Directions for future research.

Although computer touch screens can provide a wealth of accurate data they need careful programming in order to achieve their full utility. Results of Studies One to Five demonstrated that more precise measurement of children’s responses has an important effect regarding our assessment of their levels of ability. Consequently, improved data recording in a replication of Study Six which recorded the angle of pointing of children’s fingers on the touch screen would give an insight into the accuracy of children’s pointing behaviours using both Euclidean and non-Euclidean methods. This may give us the opportunity to compare children’s performance when using pointers and fingers. Research involving large scale environments (Lehnung, Haaland, Pohl & Leplow, 2001) suggests that children’s accuracy using fingers to point to locations is superior to that using compass-like apparatus. Therefore we might expect that children would display greater accuracy in pointing towards location using their fingers than when asked to use some other method such as lining up two pointers.

Most children had difficulty with construction task six as it stands. It was felt that perhaps the task was not child-friendly and that children’s lack of ability on the construction task may have reflected either in a failure to understand the task requirements or a lack of familiarity with the materials. Bremner et al. (1993) had improved levels of performance using a line-of-walk task and it is possible that a touch screen version of this might lead to a better insight into children’s ability to interpret and coordinate dimensions. Perhaps omitting the circles in both conditions and requiring construction of cues and interpretation of cues for multiple smaller locations within the touch screen areas would enable researchers to gauge accuracy as a function of distance from markers. A linear relationship between distance from the target and accuracy of response might be expected. Furthermore, such a study might, if given over a period of time, confirm the effect of success and failure of differing strategies for coding location on the weighting given to each.

This study has looked at the ability to use a Euclidean coordinate system when there is little or no spatial memory requirement. Evidence suggests that young children are indeed in possession of proximal, topological and Euclidean systems for the coding of location as postulated by Huttenlocher and colleagues and there is also support for the idea that this coding becomes less variable with age. This is predicted by Category Adjustment theory (Huttenlocher et al., 1991), which suggests that
children and adults have the capacity for both fine-grained metric coding and categorical coding of location. They suggest that the coding of location becomes increasingly hierarchical with age and that the increasing categorisation of space reduces variability and inaccuracy of estimates based on fine-grained and categorical coding. This notion of a dual system of spatial coding is supported by the findings of Kosslyn et al. (1989) who suggest that categorical coding develops with practice. Category Adjustment theory has been developed from a study of spatial memory tasks and relates to the nature of stored memories for location. CA theory suggests that distortions arise due to uncertainty of retrieved fine-grained memory for location. Crawford, Huttenlocher & Engebretson (2000) suggest that although category information is encoded for storage, categorical effects occur at the point when items are reconstructed from memory. The increasing accuracy of metric information with age found in these, non-memory tasks supports the suggestion that fine-grained coding of space becomes more exact with age although these differences could be due to differences in the child’s understanding or motivation to respond accurately.

Two possible lines of enquiry arise from these findings. Plumert & Hund (2001) suggest that children do not show bias towards category centres but towards corner of areas. This may be because they do not have a Euclidean system of location coding firmly in place to determine category centre and so bias is towards proximal or projective cues to location. The introduction of barriers does not induce prototype effects towards the centre of a space in young children (Plumert & Hund, 2001). A point of interest is whether a salient landmark would produce biases towards it and to what degree can we factor out the effect of inaccuracy as found in coordinate dimension tasks where no memory component exists. One interesting study would be to present construction and interpretation tasks with and without delay to see if salient landmarks lead to distortions towards them. Delay effects have also been noted in tests of perpendicular bias and line matching (Bryant, 1969).

Conclusion

The research reported herein suggests that young children possess a number of strategies for coding spatial location. Topological, Projective and Euclidean systems of spatial coding all appear to coexist in the young child at ages far below those that
Piaget proposes for the development of the latter of these. Selection of the method for coding location may indeed be reliant on that method's value as a heuristic.

This research also suggests that the selection of measures by which we quantify success can have a deep impact on the conclusions we draw as can the methods by which we gather that data. Altering the criteria for success and the use of more precise methods of measurement is shown to reduce some of the differences in performance seen between conditions in Lidster & Bremner's studies and reduction of scale to reduce age differences in performance. Just as the accusation has been levelled at many of the Piagetian test of cognitive ability that they underestimate the abilities of young children, it can be argued that many of the tests aimed at demonstrating spatial competence have overestimated children's competence by using techniques in which correct responses are facilitated. What is remarkable is not that children succeed on these tasks but that they fail in some instances and the biases children show in their errors are perhaps more of a key to the underlying representation of spatial location than their correct responses. In this respect the current research has more in common with that of Piaget and colleagues than initially apparent.
Reference List


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Appendix 1
Sample Permission letter

c/o Psychology Dept.,
University of Surrey,
Guildford,
Surrey,
GU2 7XH
01483 686899

Dear Parent,

I am the mother of a child who attends St. Matthew's/ The Raleigh and, having worked in education for several years, I am currently studying for a PhD at the University of Surrey. I am researching into young children's ability to use spatial coordinates. These are the skills involved in working with maps and graphs. I have been collecting data in local schools and would be grateful if you would allow your child/children to participate in this study. The study involves sitting in a quiet corner of the school and playing a simple game where the child has to point to an object on a board using two pointers. I have police clearance for working with children (Form 99). The child's age (but not their date of birth) will be recorded and all data will be anonymous once collected.

If you are willing for your child/children to participate in this study could you please complete the attached form. If you have any further queries please do not hesitate to contact me on the number above or alternatively, if you prefer, my home number: 01932 865362.

Many Thanks,

Jane M.A. Cochran

I give permission for my child/children .........................................................

to participate in this study.

Signed.........................................................Parent/Guardian

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Appendix 2
Recording sheet for Interpretation trials

Name:
Age:

Trial No.

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