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THE ORIGINS OF DETOUR PROBLEM SOLVING IN HUMAN INFANTS

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ABSTRACT

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The ability of human infants to go around a transparent barrier and retrieve a goal object was investigated. The experiments reported showed that this ability had a developmental trend for both manual and locomotor problems. Infants one year old and younger typically approach the barrier directly. By the age of fourteen months the majority of infants could solve this simple indirect problem. This trend reflects difficulty in inhibiting the direct response. Also the availability of associative groups of displacements from around one year is necessary. The possibility of success being mediated by a maturing cortical control system for reaching was discussed. In a training study infants aged eight and ten months showed no significant improvement in performance. This gave support for a maturation hypothesis.

Under certain spatial conditions it was shown that infants younger than one year can solve detour problems. Where the infant is able to displace herself by a leaning action around the edge of a detour barrier success may be forthcoming. After such a displacement the problem becomes a simple direct reaching problem. It was argued that such a solution does not show associative groups of displacements but a reversible displacement available to the infant typically from eight months of age. Spatial manipulations of the object and screen with respect to the infant affected performance in both manual and locomotor spaces. It was thought that this reflected specific task variables rather than a general expansion of behavioural space with age.

CONTENTS

CHAPTER SEVEN: PERFORMANCE ON A LOCOMOTOR DETOUR TASK IN 9-10, 11-12 AND 13-14 MONTH AGE GROUPS: SPATIAL VARIABLES THE COMPARISON WITH A MANUAL DETOUR PROBLEM

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CHAPTER ONE

THEORIES OF THE DEVELOPMENT OF SPATIAL SKILL

1:1 Introduction

This thesis is about the origins of detour problem solving. The development of the ability to go around an obstacle provides a vehicle for research in the crucial aspects of the development of spatial representation, perception and cognition. Such early abilities are the origins of cognitive maps investigated recently (Siegel and White 1975; Cohen, Baldwin and Sherman 1978 etc.) Simple detours are amongst the first indirect problems that infants encounter. Their study may provide valuable information on the development of problem solving. In addition as Bruner (1970) noted, the performance of a simple detour represents a remarkable step in the de-centring of the infant from its egocentric frame of reference. This is central to Piaget's theory (Piaget 1954).

Relatively early in the history of Psychology researchers turned their attention to such problems to investigate the nature of intelligence. Researchers in the Gestalt and Field theory traditions (Kohler 1927; Lewin 1926) were the earliest to report observations of animal and human infant subjects performing detours. Some limited observations were reported by Piaget (1953, 1954) on detour paths. Piaget's observations were made in the context of the most comprehensive theory of cognitive development to date, at around the same time as Kohler and Lewin.

More recently researchers of development in infancy have turned their attention to detour knowledge. Bruner (1970) sought to evaluate his 'modular' theory of skilled action using detour tasks. Others (Lockman 1984; McKenzie and Bigelow 1986) have sought to evaluate Piaget's stage theory and to extend our understanding of the role of detour problems in the environment of the human infant.

In this thesis, the experiments cited are restricted to investigating how human infants develop the capacity to retrieve a goal object which is not directly accessible. This inevitably involves using an indirect path to circumvent a barrier to action. These are restricted to the type reported by Kohler (1927) in which the whole situation is visible to the infant. Thus detours around opaque barriers are not investigated here, although others (Lockman 1984; Bruner 1970) have compared performance by infants on opaque and transparent barrier detour problems.

The ability to perform a simple detour around a barrier has been shown to develop late in the first and early in the second year of life of the human infant. It remains though, little understood. This thesis and the studies reported are an attempt to understand the problem of detour development. The theories which have been used to explain such development are reviewed in this chapter. These distinctive approaches are respectively perceptual (Insight and Field Theory), cognitive (Piaget) and skilled action (Bruner). Explanation at the neuro-psychological level is reviewed in chapter 2.

1.1.1 'Insight' and Detour Problems

The Gestalt Psychologist, Wolfgang Kohler described the class of problems which he investigated as 'umwege'. This is a German word which embraces 'detours, roundabout ways, paths or routes, circuitous routes and indirect ways' (translator's note to Kohler 1927). Under this heading fall such problems as locomoting around a barrier to retrieve a goal object or using tools to bring a goal object within reach. For Kohler, the objective and the overall situation is clearly seen and he excluded problems from his investigations which involve memory of necessity e.g. detour problems with opaque barriers (Lockman 1984). He further excluded maze problems and others where the initial solution is by chance. Kohler argued that the required response from animals in these and other trial and error experiments was unnatural. For example, the solution to a puzzle box problem might be to pull a lever. This action is, however, abnormal for an animal such as a cat. Kohler also excluded experimental procedures in which animal subjects move out of a line of motion which would bring them into collision with an obstacle. Such problems are related to looming and have been investigated in human infants (eg. Bower Broughton and Moore 1970; Ball and Tronick 1971) in the context of the development of depth perception. Thus for Kohler, detour problems depend upon the whole situation being surveyable by the subject from the outset.

Kohler used detour problems to study the nature of intelligence in primates in particular but also reported observations of other animals and human subjects. Importantly he contrasted the 'insight' evidenced in some of his subjects with 'chance' and 'imitation' solutions to detour solutions. The German word used by Kohler, 'einsicht' does not mean simply 'insight' but is also rendered by 'intelligence' in the English translation of 'The Mentality of Apes'. However the term 'insight' implies several aspects of the solution of a problem. The successful response appears suddenly and is easily repeated in future trials. It does not occur by trial and errror, nor by shaping or any procedure derived from the principles of learning theory. This is not to say that insight need not be preceded by errors or active experimentation since these may be necessary to discover the structure of a problem situation. This inevitably leads to instances where there is no common agreement over whether a solution is 'insightful' when other events precede it.

Insight would appear to be a kind of perceptual 'gestalt' or whole in which the subject 'sees' the potential solution to the problem. Tension in the perceptual field gives rise to instability and this can lead to a sudden reorganisation of the perceptual field to a more stable state giving the organism the solution. However as Thomson (1959) has pointed out, insight as a term has been used in two senses;

a) as a description of a pattern of behaviour observed in some problem solving situations.

b) as a name of a postulated psychological process which controls behaviour.

As an explanation of a psychological process, insight would appear to have little value. If insight comprises the reorganisation mentioned above, then Kohler failed to explain how such reorganisation happens and hence what insight as a process comprises. Other researchers in the field of animal problem solving have also pointed to the importance of the subject's previous experience and the previously existent part-processes which may contribute to problem solution (Schiller 1952; Birch 1945). However, useful contributions to the study of solutions to detour problems can be found in the Gestalt theory which Kohler espoused.

1.1.2. Gestalt Theory and Problem Solving

Gestalt theorists worked out a set of rules which sought to explain the organising principles of perception. Although over 100 rules were described by Gestalt psychologists (Helson 1933), two of the most important involved are common fate and proximity. The rule of common fate held that contours which move together in a regular fashion will be seen as the boundaries of a single moving object. The rule of common fate also applies where an observer moves but is useless in the static situation. The rule of proximity states that in an array, those contours which are closer than average will be perceived as contours of a single unit. Gestalt theorists held that such rules must be innate and it is easy to see how such innate perceptual organisation might assist in problem solving. The proximity of an implement or an opening to a goal object has been shown to assist successful tool use in infants (Bates,Carlson-Luden, Bretherton 1980) and locomotion around detour barriers (Lewin 1934; 1936). Kohler (1927) found similar results with chimpanzees. The orientation of an implement in relation to the goal or opening may asssist problem solving in apes (Kohler 1927).

On the other hand, implements and objects of similar textures and colours may make problem solving very difficult for infants. Distinctive colours and textures seem necessary in early infancy to suggest the distinction between goal and tool (Bates

Carlson-Luden, Bretherton 1980). This may reflect the perceptual processes underlying the figure-ground phenomenon. The number of elements to be combined in the manufacture of a tool increased difficulty in chimpanzees (Kohler 1927) and in human infants (Ling 1946; Richardson 1932). Kohler (1927), also cited observations of chickens failing similar locomotor barrier detours and apparently succeeding only by chance. In the phylogenetically lower chicken, he concludes that the possible detour path must not begin with the path leading away from the objective. This is in contrast to the dog and infant subjects he reported who could succeed in situations where it was necessary to turn away from the goal. Kohler concluded that detour tasks vary in difficulty according to the geometric arrangement of the barrier and goal. Thus where the barrier involves a 180° turn away from the goal, solution is less likely than where a small angle of turn is required.

Kohler concluded from his studies of problem solving that firstly, according to biological drive, organisms approach goals directly. Frustration of this (by a barrier to action), causes tension in the perceptual field whose strength is determined by the immediate physical factors in relation to the subject's psychological state. The subject's behaviour is the product of the field of forces and these unstable forces are suddenly reorganised by the perception of new possibilities (e.g. an indirect route). Kohler's failure to explain this process has led most psychologists to question the use of insight as a term describing a process and today it is generally applied only as the type of problem solving described above.

1.1.3. Field Theory

Lewin (1935; 1936; 1947) built these ideas into a more expansive Field theory of general psychological functioning. Lewin was concerned with explaining and predicting behaviour by describing the structure of forces in what he labelled a person's 'life space'. Changes in cognition , personality, motivation etc. were seen as the results of changes in the directional character of these forces or vectors. In addition to Kohler's ideas, Lewin stated that the restructuring of the field would be accompanied by a differentiation of the field into direct and indirect paths. Comparing the failure of a 1 year old child in locomoting around a U shaped barrier with the success of a 5 year old he concluded that the meaning of the direction towards the goal changes. The difficulty encountered by the younger child is due to the fact that the initial direction of the appropriate route does not coincide with the vector from the goal object. The problem is solved by a restructuring of the field so that the meaning of the direction towards the goal changes. The younger child has a less expanded life space and hence Lewin appears to emphasise the role of experience more than Kohler. Lewin also reported an observation of a 1½ year old child placed in a closed circular barrier. With no direct or indirect path available, the child turned to her mother for help. Lewin saw this as having the meaning of an indirect turning toward the goal using the mother as an indirect means of retrieval.

From this brief review it can be seen that Gestalt and Field theorists failed to account adequately for the generation of new solutions to problems. However the emphasis on perception in problem solving, particularly direct perception (Gibson 1979; Ullman 1980) in development is currently being re-examined by many researchers (Butterworth 1981). The processing of problems within perception may be more important than postulated cognitive mechanisms, especially in early development. In addition, much of the early work on detours provided valuable empirical observations on the phenomenon involved. In detour problems the indirect path to the object cannot usually be directly perceived. There may however be perceptual support or affordances as Gibson (1979) termed them. The detour path must be inferred either in perception or cognition. The role of perceptual support in such inferences is discussed in depth later in this thesis.

1.2. Piaget's Theory of Sensorimotor Development

According to the theory developed by Piaget, knowledge develops out of an interaction between innately given cognitive structures and the external environment. This interaction is governed by a need to impose the internal structures on as many aspects of the environment as the organism meets. This is a functional invariant of all living organisms. Piaget calls this functional assimilation. Every attempt to assimilate the environment to a particular structure or schema is constrained by the nature of the structure itself. Each schema can only represent a portion of reality itself. Consequently, attempts to assimilate aspects of the environment outside their domain will fail. Piaget's theory proposes that a second functional invariant is the tendency to achieve equilibrium. Thus when a schema fails to assimilate a particular environmental situation the organism is thrown out of equilibrium. To re-esablish equilibrium, the organism is forced to modify its particular schema in a direction determined by the the environmental situation. This process is termed accommodation.

Thus Piaget's most basic thesis is that all living organisms maintain a state of equilibrium through the processes of assimilation and accommodation. In the sensori-motor period (roughly 0-2 years) these processes bring the child from an initial state of radical egocentrism or solipsism to a point where the spatio-temporal properties of the world are perceived and can be represented in cognition. The world has no meaning for the neonate who perceives no distinction between itself and environment. Experience comprises a series of 'perceptual tableaux' which come and go with no meaning connecting them. Piaget sees the development in the sensori-motor period as comprising the increasing co-ordination and elaboration of schemas of action. The mechanism whereby the infant achieves this new adaptation is called by Piaget (1953) the circular reaction, a concept he borrowed and adapted from J.M. Baldwin (Baldwin 1925). The circular reaction is a regular pattern of action which ends at its point of departure, hence it is circular. There are in Piaget's view primary, secondary and tertiary circular reactions. The distinction between these will become apparent in the review of another central feature of Piaget's theory, the stages of development. In development there are four main stages of intellectual development, (ages in brackets are approximate), sensori-motor (0-2 years), pre-operational thought (2-7 years), concrete operational thought (7-12 years) and formal operational thought (12 years onwards). Here we are only concerned with the sensori-motor stage. The important point is that stages in Piaget's theory represent qualitatively different forms of intelligence. In addition, new stages are built on the properties of the preceding stage.

The sensori-motor stage is divided into 6 sub-stages (hence-forth termed stage). Each of these 6 stages is characterised by the most advanced behaviour found in it. However behaviours from the previous stages are to found in each stage or they may be directly integrated into more highly adapted schemas characteristic of the new stage. The principal achievement of the infant in Piaget's view, is the development of the object concept. The construction of the spatio-temporal identity of objects is necessary to the further developments of mental representation and hence thought and the symbolic functions (especially of language. To explain the theory further it is necessary to briefly review the properties of the respective stages and in doing this those most relevant to the investigatiorn of detour knowledge will be emphasised. In particular, the development of the object concept and the related spatial and means-ends stages of development will be described. This review is of necessity brief and a more detailed review is available in Flavell (1963) or Butterworth (1981).

1.2.1. Stages of Sensorimotor Development

Stages I and II: 0-3months

Initially the infant exists in what is purely a practical space as opposed to the later development of subjective and objective space. The infant is born with innate reflexes which, when co-ordinated together form a primary circular reaction. An example of this would be when the infant brings her hand to her mouth in order to suck it. The infant is aware only of her action and not of the objects to which her action is applied. The characteristic response to the disappearance of an object is the continuation of the infant's accommodatory movements. For example, she would typically continue to stare at the place of an object's disappearance. The practical spaces, buccal, visual and auditory are unconnected. It must be noted immediately that research in many different areas, notably reaching (e.g. Bower 1972), auditory-visual co-ordination (Butterworth and Castillo 1976) and imitation (Meltzoff and Moore 1976) has shown that the characterisation of the infant as a solipsist is inaccurate.

Stage III: 3-9 months

The co-ordination of primary circular reactions gives rise to secondary circular reactions in this period of subjective space. The secondary circular reactions are an advance in that they are outwardly directed and not just centred on the infant's own bodily activities. The stage III infant becomes able to formulate goals but still fails to dissociate her actions from the desired response. For example when Piaget observes an infant grasping an object she swings her hand to and fro. However, on dropping the object she repeats the movement in an attempt to re-create the object. In this instance, it is her act of swinging which constitutes the object. The object still has no permanence of substance, spatial or temporal, independent of the infant's action.

The principal achievement of stage III is the emergence of the ability to separate means from ends and hence the first signs of intentionality. In the object concept the infant begins to anticipate future positions of objects but fails to retrieve a hidden object. Locked into the undifferentiated action × object schema, the infant fails to conceive of an object existing outside her immediate experience. Hence the characterisation 'out of sight is out of mind' in this stage.

Stage IV: 9-12 months

The stage IV infant has made substantial progress in the area of spatial development and the object concept. Through the co-ordination of secondary circular reactions the infant is able to differentiate means from ends. The infant can remove a cover from a hidden object and this indicates the transition to objective spatial understanding has begun. The spatial relation is only partly understood though. The characteristic stage IV error indicates that the infant's conception of the object is at one place only. An object hidden at a location A and retrieved by the infant is subsequently hidden at a separate location B. The stage IV infant searches at the original location A in spite of having seen the object disappear at B. For Piaget this shows that the infant still believes that its act of retrieval at A recreates the object. This test is crucial to Piaget's theory, that in infancy, objects are not perceived as having spatio-temporal identity. The importance of the stage IV error has generated a large volume of research (see Butterworth 1981 for a review) testing Piaget's theory with alternatives.

During stage IV, there is importantly, evidence of the discovery of perspectives or changes in shape of objects from different perspectives. Piaget noted:

'At 0;11 (23) Jaqueline is in her baby swing and perceives her foot through one of the two openings for thew use of the legs. She looks at it with great interest and visible astonishment, then stops looking to lean over the edge and discover her foot from the outside. Afterward she returns to the opening and looks at the same foot from this perspective. She alternates this five or six times between the two points of view' (Piaget 1954 obs. 91.).

Piaget describes other situations where the stage IV infant can, through displacement of the self, relocate hidden objects;

'At 0;9 (30) he leans sideways to see his bottle hidden behind my raised arm.' (Ibid. obs. 99.)

This would appear to be the first example of the solution of a hiding problem with an opaque barrier. This schema may permit the solution of detour problems without the later development of associativity. This is discussed in detail in the next section. Being able to recover an object from behind a screen manually or visually would seem to constitute the same structure of reversing an occlusion. The manual and visual schemas for retrieving a hidden object also appear at around the same time. However, such achievements do not automatically generalise to all spaces of whatever scale. It is only with experience of locomotion the distinction between near and not-so-near space begins to be ended.

Stage V: 12-18 months

In this stage the infant's understanding becomes further objectified. Through the new mechanism of tertiary circular reactions the infant is able to vary its actions upon objects in order to see what effect such variation has. This is an advance over the secondary circular reactions which were restricted to repetition without variation.

Although the infant in stage V is able to retrieve an object accurately when it is hidden successively at separate locations, the spatial relations between self and objects are still not mentally represented in an entirely objective way. The infant learns to search where an object was last seen but cannot take account of hidden displacements of objects. For example if an object is transported in a closed hand and placed behind a screen, the infant will look repeatedly in the hand where she saw the object disappear. She is unable to infer a hidden movement. In the AB situation of the stage IV error, if the object is hidden at A and the A and B covers are switched in absolute location, the infant will search inaccurately at the original location of A.

Stage VI: 18-24 months

The development of mental representation becomes possible in this final stage of sensori-motor development. The inference of the position of a hidden object across successive invisible displacements indicates the availability of mature spatial representation and a complete object concept. New means of solving problems are available through internal mental co-ordination. Such mental co-ordination makes possible the develop ment of the symbolic function and hence language and more elaborate cognitive functioning.

1:2.2. Detour Knowledge and Piaget's Theory of Space

Piaget's theory of the development of intelligence is based upon intense observation and experimentation. However underlying the theory is a particular epistemological view. Embedded in that view is a particular system of logico-mathematical resoning. Thus central in spatial understanding Piaget uses the term 'group' in a particular sense derived from logical algebra. This view and its developmental implications for detour understanding are reviewed below.

For Piaget the nature of spatial knowledge is characterised by four operations; i. composition, ii. identity, iii. reversibility and iv. associativity (Piaget 1952; 1954). These structures form a mathematical group, making a stable, self cancelling stucture. In spatial terms these operations translate into the ability to ;

i). combine separate displacements AB and BC into a single displacement AC (compositiion).

ii). return to a starting point (identity) .....

iii). by an inverse action (reversibilty).

iv). reach a point in space by combining a potential series of displacements in a variety of ways, enabling an infant to perform detours (associativity).

Piaget's own observations of infants performing detours help to elucidate the meaning of these algebraic terms. These observations were made on infants during sensorimotor stage 5 (12-18 months approximately). The detours involved locomoting from one position to another by a path other than the direct route. In the case of the route described below, Piaget (1954 obs. 117.) noted how his son Laurent at 1 year 2 months of age constructed the group of displacements described above.

> *'Here are two examples; The first is related to a gate which attracted him every day during his walk in the*

garden. To reach gate P, he was obliged either to follow two paths, AB or BP, together describing a right angle at point B, or to follow the rectilinear trajectory AP by going directly through the grass. At the beginning of his daily outings, when Laurent arrived at A he looked from afar at gate P, but thought he had to follow the trajectory ABP in order to reach it. Moreover he returned by the same path, extending line BA to reach another gate at the opposite end of the garden. After a few days he began the return trip by following line PA, whence the group AB, BP and PA. Next he followed the same itinerary in the opposite direction, AP, PB, and BA. Thus it may be seen that an actual group is constituted by the child's own displacements.'

Piaget however concludes that such displacements are not achieved by mental representation of possible displacements. The child in this instance, only became conscious of the spatial relations between points A,B and P, indicated by environmental landmarks such as bushes and his own displacements through what he described as 'directed groping'. Thus Piaget writes;

'.... when the child is at P he sees from far off certain signals at A which permit him to follow trajectory PA in a straight line, without knowing that he thus sums up, in a single operation the two displacements PB and BA.' (ibid. obs. 117.)

It would appear from Piaget's limited observation that the group property of associativity first appears in stage 5. Reversible displacements can be observed in the stage IV infants ability to remove a cover hiding an object and as noted earlier, displacing the self to visually recapture a hidden object. There are however limitations which apply to the application of associativity in stage V.

One such limitation is that knowledge is only applied where the infant can perceive the various routes directly. The application of associativity to potential routes which are not entirely visible must await the development of true mental representation in stage VI (roughly 18-24 months). However, Piaget indicates that even in stage 5 the child may retrieve an object by following the object's path of disappearance. This is demonstrated in an observation of his daughter Jaqueline aged 1 year 4 months:

> *'She watches me as I put her duck behind my back: she rises and goes around me methodically to look for it' (Piaget 1953. obs. 167.).*

This behaviour was distinguished from true displacements which are inferred and show a genuine representation of the spatial interelations of objects as well as displacements of the body. Later at 1 year 6 months Jaqueline showed the true representation of space when she recovered an object using a different trajectory from that of the object's disappearance.

From Piaget's observations it can be inferred that detour knowledge can be seen in the stage V infant but not until stage VI for detours where part of the situation is not visible. There are though limitations to these conclusions. Firstly, Piaget did not observe detours where a transparent obstacle separated the infant from the goal object. Hence it cannot be asserted that the infant would not become pre-occupied with attempting to remove such barriers to action. However the observations reported indicate that the stage V infant could in theory make a detour around a transparent barrier. Secondly, Piaget did not observe detours in a reaching space. Hence no conclusions regarding the generalisation of detour knowledge can be made.

1.2.4. Research on Piaget's Theory and Detour Development

Lockman (1984), is the only researcher to date to systematically investigate the relationship between detour knowledge and stage of development as measured by object permanence tests derived from the Uzgiris-Hunt (1975) scales. Lockman investigated 12 infants longitudinally from 8-12 months of age. Success on any test was only scored if the infant retrieved the goal object on 2 out of 3 trials. The experimenter tested the infants for progress to stage IV and stage VI and success on manual and locomotor detour tests with both opaque and transparent barriers.

The results of Lockman's study indicated that contrary to Piaget's prediction, infants solved opaque barrier problems prior to transparent barrier problems. This accorded with Bruner's results (Bruner 1970). Progress to stage IV of object permanence was achieved by all infants prior to success at any detour problem. In contrast, none of the infants progressed to stage VI before success on all of the detour problems. Lockman was careful to avoid the infant following the perceived trajectory of the object as it was placed behind the barrier. In each detour task the object was moved behind the barrier by a trajectory over the barrier, a trajectory which was impossible for the infant to imitate. Thus either the opaque barrier problem involves different processes than those postulated by Piaget (ie. mental representation) or the Piagetian tests and theory themself must be questioned.

From this section it can be concluded that success in detour tasks in which the whole situation is visible does not conflict with Piaget's theory. In contrast, research on opaque barriers does conflict with the theory that spatial representation, not fully developed until stage VI, is required for such tasks. However, research on how infants learn to solve detours has not been undertaken to date. Such research is essential to fully evaluate these limited conclusions.

1.3. Theories of Motor Skill Development

The concept of skill, as Connolly (1977) has pointed out, covers a wide range of performance including fine manipulative skills such as tool use (emphasised by Paillard 1960), perceptuo-motor skills and gross bodily movements such as locomotion. The concept has been used to include social skills and of particular importance here, problem solving.

The term skill implies that the execution of a particular behaviour is characterised by efficiency, accuracy and is goal oriented. In the area of motor skill, it is necessary to distinguish between actions, movements and skills. Connolly (1977) emphasised that an action implies an intention to act. Skill involves the construction of a programme of action. The basic unit of an action programme by computer analogy is a sub-routine (Bruner 1970; 1973). Such a programme is not simply the movement of muscles, which may constitute the end product of that programme. As an agent a person may intend to pick up an object but she does not intend to move certain muscles by firing certain efferent nerve fibres as such. The distinction between problem solving and skilled performance can be described on this view as the difference between the organisation and the execution of such an action programme (Elliot and Connolly 1974). Thus a well practiced skill requires execution but its organisation may in routine circumstances require little if any problem solving.

Skilled action must be organised spatially and temporally. Such organisation not only requires the production of a programme or plan but the monitoring of that plan or programme during and after execution. Thus, the role of feedback during the execution of an action and feedback of the consequences of an action have been seen as vital components of theories of skilled action. In addition, feedforward signalling outcomes of an intended action must be incorporated into any model accounting for planned actions and hence voluntary movement. In particular some form of feedforward is necessary for a new solution to a detour problem to be programmed effectively. The models of particular interest in this area are those of Bernstein (1967), Adams (1971) and Schmidt (1975).

The model due to Bernstein has advantages over some others (Adams 1971; etc.) in that it appears more adaptable to the problems of voluntary activity. However it does not take into account the role of visual and other perceptual feedback. Bernstein proposed that a minimum number of elements must be present in a control system capable of voluntary activity towards objects or aspects of the environment. These are:

a) effector (motor) activity, which is to be regulated along the given pararmeter

b) a control element which conveys to the system ..... the required value of the parameter to be regulated.

c) a receptor which perceives the factual course of the value of the parameter and signals it by some means to

d) a comparator device which perceives the discrepancy between the factual and required values with its magnitude and sign,

e) an apparatus which recodes the data provided by the comparator device into correctonal impulses which are transmitted by feedback linkages to

f) a regulator which controls the function of the effector along the given parameter' (Bernstein 1967)

This model assumes that an exact copy or motor image of any proposed movement must exist in the nervous system. This is necessary to facilitate the feedforward which anticipates consequences of actions prior to their implementation.

In contrast to this Adams (1971) proposed that motor learning involves the memory trace and the perceptual trace. The memory trace forms a motor programme which initiates action whilst the perceptual trace formed from past experience with feedback represents the sensory consequences of the movement. The individual compares feedback from actions against her perceptual trace and on the basis of this comparison, any necessary adjustments are made. One of the principal drawbacks of this model is that it requires a motor programme for every movement and is thus hopelessly uneconomical. Further Adams is concerned with laboratory phenomena and not the real world skills of infants (Hogan and Hogan 1975). Finally, the model cannot account for learning without knowledge of results which Bernstein incorporates and which von Holst (1954) pointed out involves the idea of efference copy.

Partly to deal with the problem of economy, Adam's model was extended by Schmidt (1975) who assumed the existence of generalised motor programmes. In addition Schmidt's model incorporates the concept of a schema, originally suggested by Head (cited in Bartlett 1932) and in particular motor response schema. The individual uses the schema to generate a response specification and also generates expected sensory consequences, both proprioceptive and exteroceptive. During or after the movement, these may be compared with the real feedback and the required modifications made. Thus Schmidt's theory can account for both open and closed skills.

The problem of accounting for the origins of schemas, fundamental to the study of the development of motor skills is not addressed adequately in Schmidt's model. Practice of either the means of solution or of the process of solving requires an initial solution to be practiced. Thus Bruner et. al. (1968; 1970; 1972) examined the pre-adaptation of motor skills, their sub-structures and combination to produce co-ordinated action patterns.

1.3.1 Bruner's Modular theory of Skilled Action.

A central feature of Bernstein's (1967) theory is that the achievement or 'mastery' (Bruner 1970) of control always involves a reduction in the degrees of freedom in the action system being regulated. With the process of 'modularisation' an act becomes more automatic and smooth. This is central to the infant's growing ability at organising skilled action. Once an act is modularised it can be incorporated into other action programmes. With practice, the modularised act enables freed information processing capacity to be used to co-ordinate such modules or sub-routines (Connolly 1977) into higher order and more specialised programmes.

Some of the constituents of new skills are pre-adapted (Bruner and Koslowski 1972). These appear to develop autonomously, without environmental reinforcement but none-the-less appear clumsy and awkward initially. With practice such skills are modularised and incorporated as indicated above. Modular response patterns may also be differentiated from grosser motor patterns, as shown in the development of complementary two-handedness (Bruner, Lyons and Watkins 1968).

The combination of modules into a programme is initiated by a guiding intention. This holds the goal invariant while means are varied to its achievement. Bruner, citing Lashley (1951), emphasises the appropriate serial ordering of modules for effective problem solving. Thus, in contrast to Piaget's theory of sensori-motor co-ordination, Bruner proposes that early learning is essentially problem solving.

> *...the issue in visual-motor co-ordination has not to do with the integration of two seperate sensory systems or modalities, but rather with the differentiation and serial ordering of the constituent acts involved in achieving an objective like object capture. (Bruner and Koslowski 1972)*

This theory has been tested specifically in relation to detour reaching.

1.3.2 Detour Knowledge and Bruner's Theory

In the context of his theory of skill acquisition Bruner (Bruner 1970; Bruner, Kaye and Lyons 1968, (same study)) investigated the nature of manual detour reaching. In this study the infant was sat in front of a vertical screen which was either transparent or opaque. The screen was either at the infant's midline or 4 inches across the midline to the left or right side. The goal object was placed in successive positions relative to the screen either in the open space or behind the screen. Thus with a transparent screen a barrier to action was present but with the opaque screen, a barrier to perception was there for the infant as well. Infants tested were divided into 3 age groups, 6-9 months, 10-13 months and 14-17 months, 40 in each group.

In evaluating the theory described above, Bruner analysed the following 4 task demands of the situation:

1. The infant must appreciate the spatial demands of the task in terms of means rather than goals.
2. The infant must dissociate the line of action from the line of sight.
3. The infant must have the capacity to shift action programmes when success is not forthcoming.
4. The infant must be able to sequence a series of instrumental means to an end.

In relation to these task demands, Bruner described the predominant strategies of the age groups and discussed them in terms of the pattern of use of the ipsilateral and contralateral hands. The predominant initial strategy of the youngest group was to reach directly towards the object along the line of sight. This was usually done with the ipsilateral hand, in most conditions that is the inappropriate screenside hand. This ineffective action was often followed by banging or scratching at the barrier and then quitting. The contralateral hand, appropriate to the task often remained at the infant's side during this activity. In the youngest infant group, shifting programme proved more difficult in the face of failure.

In contrast, infants in the 10-13 month old group would often move the ipsilateral hand from where it rested on the screen, to the screen edge. After this the hand reached around the edge in an awkward backhand reach. On other trials the ipsilateral hand would first bang at the barrier and eventually the contralateral hand would be recruited to reach around behind the screen successfully. The infants in the oldest group would nearly always reach immediately in a detour path for the object with the contralateral hand. From this synopsis of Bruner's study it can be seen that success at the four task demands has a developmental character.

Appreciation of the spatial demands of the test increased with age. Long screens (extending across the infant's midline), proved more difficult than short screens (at the infant's midline) for the young and middle age groups. The position of the object in relation to the screen edge was also a significant source of variance. Whilst older infants were capable of circumventing the barrier at all object positions, for the young infants success was rarely achieved unless the object was close to the edge of the screen. Bruner concluded:

'The behavioural space within which the child solves the detour problem seems to expand with age.'

Although the predominant response of 6-9 month infants was as might have been expected by Piaget (1954), none-the-less, Bruner reported considerable success by infants who, by their age we would not expect to have reached stage V or VI in sensorimotor development. As explained earlier, Piagetian theory predicts that transparent barrier tasks would require the means-end co-ordination of stage V. Opaque barrier tasks would require the spatial representation of stage VI infants. In any event success at less than 12 months of age requires a careful re-examination of the theory, predictions and results. In Bruner's study, even in the 6-9 month age group 30% of infants achieved immediate freehand success. This compares with 50% for 10-13 month olds and 67% for the oldest age group. These results were summed across opaque and transparent screens.

The source of at least some of this clear discrepancy with Piaget's theory is hinted at when this finding was broken down between success in transparent and opaque barrier trials. For the 6-9 month group, opaque barriers were easier than transparent barriers. This is even more in conflict with expected results. This trend was reversed in older infants who found transparent barriers easier than opaque ones, at a higher baseline success rate overall. This may be explained by Bruner's second task demand, the dissociation of the line of action from the line of sight. Most of the young infants initially reached directly to the location of the object in transparent barrier trials. Older infants used the visual information to locate the object in a detour reach. The opaque barrier does not require the young infants to inhibit direct reaching so shifting programmes is less of a problem in that condition.

A further clue to the disparity with predictions from Piagetian theory is given by Bruner when he notes that opaque screens force the infant to lean around the edge of the barrier to locate the object visually. The presence of the object in opaque conditions was indicated by jiggling a bell in the toy used as the object. As noted earlier, Piaget (1954) observed stage IV infants displacing their line of sight (i.e. leaning around the barrier) to recover sight of a hidden object. Using such a strategy, the infant has converted a detour problem into a line-of-sight problem. It follows from the geometry of the apparatus that this strategy will be more successful in object positions close to the edge of the barrier and for midline screens. Although Bruner does not mention the use of a 'leaning' strategy with transparent screens this remains a possibilty and this will be discussed in chapter 2.

The ability to shift action programmes again showed a developmental trend. Young infants typically began using the inappropriate ipsilateral screenside hand and when this proved ineffective, were unable to shift to contralateral hand use. Older infants were able to shift with increasing ease to a high level of performance where the ipsilateral hand was not brought into play at all. Bruner referred to this as 'pre-emption by ongoing action'. He noted that young infants were none-the less able to recruit the contralateral hand in assistance to attack the barrier.

The fourth task demand concerned the serial ordering of behaviour. Most of the young infants attempted to get at ends without organizing a sequence of means appropriate to the task. However, with so many other variables in the study this ability is difficult to evaluate. At least some young infants are capable of sequencing appropriate means as evidenced by the successful 'leaning' strategy. Also attempts at removing the barrier show an ability which is only unsuccessful because the screen is fixed. Infants in Piaget's stage IV are able to remove a barrier and then retrieve an object from behind it. Thus it may be that sequencing is not a general but a specific problem. That is the question to be asked should be - 'what is sequenced and how?' The lack of ability to 'de-centre' away fron the egocentric line of sight would appear to be the young infants problem. Removing a barrier to action or perception is in one sense a modification of the line-of-sight strategy and hence can be seen as only a small step along the developmental path to spatial representation.

Kaye (1980), using the same apparatus as Bruner, Kaye and Lyons (1968), studied infants' effects on their mothers' teaching strategies. Although only incidentally interested in the detour task, Kaye found that prior to training 19% of his 6 month old subjects succeeded at least once in a pre-test. The barrier was transparent, situated at the infant's midline and the object was placed just in behind the screen. In post-training tests, 34% succeeded in retrieving the object. This was however not related to training, the only predictor of post-test success being success on the pre-test. On a transfer test, with the screen placed on the opposite side to previous tests and training only 21% of subjects succeeded.

Whilst providing valuable information on the nature of mother-infant interaction in a training task, the study again raises the question of how some 6 month infants succeed at a detour task in a seemingly precocious manner. A clue is provided by Kaye's observation that infants would frequently reach out into the open space of the apparatus. Contact with the object in close proximity to the edge of the screen may have been accidental. It is further possible that infants used a leaning action of displacing the self to solve the problem. With the screen at the midline and the object close to its edge, a relatively small movement of the head and trunk would render the problem amenable to a direct line-of-sight solution.

In the context of the 'modular' view of skill advanced by Bruner (1970) the developmental advances demonstrated by Bruner, Kaye and Lyons (1968) and Kaye (1980) in detour reaching support some aspects of the theory. In particular, the units or modules of skilled reaching have been shown to free the limited information processing capacity of the infant when practiced. The increased availability of information processing capacity may then be used to analyse and respond to feedback from unsuccessful action. Thus a 'modularised' action like reaching and grasping, may, in the older infant be incorporated into a more complex programme. In the detour test feedback may permit the generation of a new programme specifying 'reach away from the object, through the open space, then in towards the object and grasp to recover'. However the Bruner and Kaye studies fail to analyse in detail how infants succeed. Here it has been suggested that success in young infants up to 12 months may be forthcoming by fortuitous accident or random experimentation and not by the generation of such a programme. Further as noted, a stepwise action of displacing the self and hence the line of sight to remove the 'behind' relationship of barrier and object may be employed by the infant. The ability to shift strategy implies that the action is strategic and that an alternative action is available. Young infants may not be able to demonstrate an abstract ability of shifting strategy because no other action is available. This may reflect the immaturity of underlying perceptual and cognitive structures not discussed by Bruner. Further the implicit assumption of a strategy implies a level of reflection which itself is developmental in character. Thus Bruner's anlysis requires some additional conceptual clarification. Such clarification is more readily available in the theories of Piaget (1954) and Gibson (1979).

1.4. Summary

1. This thesis concerns the development of the ability to solve detour barrier problems where the whole problem is visible. Three alternative theories used in the explanation of development of detour problem solving were described. These were related to research on simple detour problems where an object is to be retrieved from behind a transparent or opaque barrier.

2. Kohler's theory relating 'insight' to detour problem solving was described. It was concluded that the concept of insight as an explanatory device for the appearance of new problem solutions is inadequate. A more detailed analysis of perceptual processing would be required to examin the value of insight as process.

3. Piaget's theory of sensorimotor development was described. Observations and intellectual structures relevant to detour problems were reviewed. On this view the development of associativity in Stage V was necessary for the solution of simple detours with transparent barriers. The development of spatial representation in Stage VI was necessary for the solution of detour problems with opaque screens. The possibility of solving detour problems in Stage IV by the application of reversible displacements to reinstate the sight of a hidden object was raised.

4. Bruner's skill theory was placed in the context of motor skill theory. The relationship between innate constituents of problem solving and the organisation of sub-routines into programmes af action was discussed. The theory was related to manual detour problem solving.

5. The study of infants solving detour problems has shown that such solutions are common after one year of age but may occur earlier. The characteristic response in early infancy was a direct approach to the object without taking account of the barrier. However studies have shown infant success prior to 1 year (Bruner 1970) where infants may use reversible action schemes and in longitudinal studies (Lockman 1984) where in addition practice effects may be important.

CHAPTER TWO.

ASPECTS OF PERFORMANCE ON DETOUR PROBLEMS TASK VARIABLES AND PREDICTIONS FROM THEORY

2.1. Introduction: Motor Skill and Spatial Development

The relation between the visual world and the world in which we actively move and manipulate things has been the source of discussion and research for centuries. The Kantian view is that space is an innate amodal representation on to which different modalties are mapped. Directly opposed to this view is the Empiricist view of Berkeley (1709) which proposes that the visual world of the infant is a series of unconnected tableaux. Experience, on this view is necessary to perceive such fundamentals as the third dimension. Between these views come those of most contemporary Psychologists. For Piaget (reviewed earlier) the spatial modalities develop independently and must be gradually be assimilated. Another position adopted by Gibson (1966) holds that perception is direct and it follows that the development of motor skill is learnt within a framework of pre-existing perceptual competence.

Such a variety of theories have implications for the development of detour knowledge. The development of motor skill is on Piaget's view (Piaget 1954) an aspect of the circular reaction mechanisms through which the infant constructs perception. On the other hand for Gibson (1966), pre-existing perceptual structures are able to detect directly the third dimension and other spatial invariants. Such a theory complements the theory of skill development outlined in chapter 1 (Bruner 1973). The pre-adaptation of skill to perceived affordances of objects or relations between objects are part of the same system. On either view the problem of whether a detour path is discovered in perception or action must have its roots in previous motor skill development and its related perceptual structures. The development of motor skill related to detour problem solving is reviewed next to examine the origins of indirect behaviour.

2.1.1. The Development of Locomotion

Locomotion has been seen as vital to the development of perception (Piaget 1954; Held and Hein 1963). Thus the development of locomotion is of important when examining processes involved in the solution of detour problems. Shirley (1931) described 5 principal sequences of motor development in human infants:

a) The development of passive postural control which is achieved by 5-8 months for sitting and 11.5-17.5 months for standing.

b) The development of active postural control.

c) Active attempts at locomotion.

d) Locomotion by crawling at 7-11.6 months and walking with support.

e) Walking unaided at 11.6-17.5 months.

Early investigations on stair climbing (Gesell and Thompson 1929), rearing Hopi infants on cradle boards (Dennis 1940) and toilet training (McGraw 1940) indicated that locomotion and other motor behaviour was determined by maturation. Gesell (1954) suggested that such the ontogeny of behaviour such as locomotion could be explained using four principles:

1) Individuating maturation, that the growth impulse is endogenous.

2) Developmental direction, that trends exist along the cephalo-caudal (head to tail) and proximal-distal axes.

3) Reciprocal interweaving, which follows the example of antagonistic muscles (extensors and flexors) alternating in movement.

4) Self-regulatory fluctuation, which allows the co-existence of stability and variability as complementary processes.

The basic maturation hypothesis was substantially unchallenged until Bower (1974a) asserted a developmental hypothesis relating early reflexive behaviour and later voluntary controlled movements. Of interest here is the investigation of primary walking. These early rhythmical walking movements disappear at around 2 months of age (Zelazo, Zelazo and Kolb 1972). Infants do not generally show secondary (true) walking until around one year (see above). However, when primary walking is exercised, secondary walking is accelerated (Andre Thomas and Dargassies 1952; Zelazo, Zelazo and Kolb 1972). In extending these ideas, Zelazo (1983) has proposed that the conversion of neonatal stepping behaviour into instrumental behaviour is a necessary prerequisite of secondary walking.

2.1.2. Movement and Spatial Knowledge

The importance of self-produced motion in the development of space perception has been tested in several experiments. Of these the most elegant is perhaps the procedure using the apparatus known as the kitten carousel (Held and Hein 1963). This can only be used where ethical considerations permit the possibilty of permanent damage to the new-born. The human infant could not be used in this procedure and the experimenters chose kittens as subjects. Results concerning the development of perception in kittens cannot be assumed to generalise to other species including man.

On the kitten carousel, two kittens were yoked in a circular environment. This was arranged such that one kitten actively locomotes causing the second to move identically but passively. The kittens were raised in the dark for 8-12 weeks and then placed in the apparatus for 3 hours a day for 10 days. After this period the kittens were tested for perception of depth and the results showed that only the active kitten could demonstrate depth perception.

Depth perception can be demonstrated in normal kittens at around 3-4 weeks. Miller and Walk (1975) showed that repeating the procedure earlier in the kittens' lives produced only a slight delay in depth perception measured by a visual cliff test (see below). Hein and Diamond (1971) have reviewed this area of animal research comprehensively. Other methods are needed to investigate development in human infants. One such method is the apparatus known as the visual cliff.

Gibson and Walk (1960) and Walk and Gibson (1961) placed human infants on a flat glass surface beneath which a deep step was visible. The researchers reasoned that having no experience of transparent materials the infant subjects would show fear at the drop if they could perceive depth. Fear was identified by an increase in heart rate and physical avoidance behaviour. Using avoidance measures, Gibson and Walk (1960) found that infants were aware of depth very early in life but not innately.

Campos, Hiatt, Ramsay, Henderson and Svejda (1978) observed a decrease in heart rate by non-crawling 5 month old infants but an increase by crawling 9 month olds. These results indicated that pre-walking infants could perceive depth but did not fear the drop. Campos et al (1978) concluded that the development of depth perception in pre-locomotor infants must be due to passive movement. In contrast to this view, Rader, Bausano and Richards (1980) showed that crawling infants would cross the visual cliff utilising tactile information under some circumstances. In their study Rader et al (1980) showed that infants who had received locomotor experience in a baby walker would not cross the visual cliff. However, infants who had begun to crawl before 6.5 months crossed over whilst later crawlers did not. Nearly all infants who crossed when crawling would not cross in the baby walker. Early crawling appears to generate a programme using tactile cues. Later crawlers use a visuo-motor programme to direct the shift of weight onto the hands in response to visual cues specifying support.

Analysis of the cues that specify depth shows the visual cliff is a complex perceptual situation. Differential texture gradients are generated as an identical pattern appears smaller when viewed at a distance. This cue is supplemented by information from motion parallax. Motion parallax is generated by movement of the head. Near objects appear to 'move' faster than distant objects but as Gibson (1950) pointed out this movement depends upon the relative distance of the viewer's fixation point as well. These two cues to depth are confounded in the standard visual cliff test. They can be distinguished by comparing responses to an enlarged texture at the deep end of the cliff which retains the possibility of motion parallax but renders the projected density of texture across depths equal. Studies show that all species tested (Walk and Gibson 1961), including human infants (Walk 1966), can use motion parallax to specify depth. However Fantz, Ordy and Udelf (1962) provide a note of caution. Whilst the visual acuity of the infant may be adequate in static conditions, dynamic visual acuity necessary in the perception of motion parallax may not be fully developed in early infancy.

Other cues specifying depth include visual occlusion and linear perspective. However as pointed out by Bower (1974a) these cannot give absolute specification of depth. Visual occlusion can only specify whether an object is in front of another relative to the observer's point of view. Perspective cues and texture gradients can only specify relative distance (Gibson 1979) but are vital in visual proprioceptive mechanisms in postural development (Butterworth and Hicks 1977; Butterworth and Pope 1983). The only cue which specifies absolute distance is the angle of convergence between the two eyes when focussed on an object. As Bower (1974a) pointed out, binocular disparity, the displacement of the image of the non-fixated object provides only relative cues. Even the calculation of the depth of binocular convergence depends upon an intrinsic knowledge of the distance between the eyes. This distance grows with age and hence the system must be re-calibrated over time. Finally, Gibson (1979) noted the possibility that motion parallax using the nose as a constant near object might provide a cue to absolute distance.

2.1.3. Reaching and Spatial Development

Important to any theory of spatial understanding is the development of reaching skill. Long before independent locomotion becomes possible, the human infant actively explores her world manually and visually. For Piaget, reaching involves a mapping of of visual and manual schemas (Piaget 1952). On this theory, early reaching is characterised by alternating glances from hand to the object. The infant approaches the object with a series of small visually guided movements before capture.

White, (White 1963; 1971) has conducted several research programmes in a similar framework. White sees the ontogeny of reaching as the co-ordination of a number of initial co-ordinations including touch-grasp, eye-hand and eye-arm. However it is important to note that White's theory was based on observations of institutionalised infants in a visually unstimulating environment. White's co-ordination theory, although essentially similar to Piaget's differs in that for White environmental factors are central co-ordinating forces. For Piaget, the equilibration of the child's assimilation and accommodation to the environment are the motive forces behind development.

White tested the role of experience in the development of reaching. By greatly enriching the environment, White reasoned that infants would not go through the all important repeated hand regard. Instead their visual attention would be drawn to the environment. However, with the enriched environment from 37-124 days the infants showed accelerated swiping and anticipatory grasping. Hand regard did not begin until the hand was seen in contact with an object. Hand regard cannot thus be seen as a necessary precursor of reaching and grasping. A second group of infants received two pacifiers in the visual field from 37-68 days. Even in this group anticipatory grasping was accelerated and in both groups appeared before tactually elicited grasping. Thus White demonstrated considerable environmental effects in the development of reaching, but they did not support the type of environmentalist theory he espoused.

In contrast to White's environmentalist viewpoint, Humphrey (1969) noted the phenomenon of visually elicited reaching in human neonates. This form of reaching is characterised by its ballistic nature. The infant, having commenced her reach cannot adjust it during execution. This visually elicited reaching disappears at around 3 weeks of age and re-appears at around 4-5 months. As in the case of neonatal walking (McGraw 1943), Humphrey has argued that this disappearance is due to the takeover of reaching by cortical centres in the brain. This process involves the growth of inhibitory dendritic connections from the cortex to the motor centres first. These are only followed later by excitatory dendritic connections reinstating the original motor behaviour under voluntary control. Thus the behaviour disappears and on re-appearance is under cortical control which enhances co-ordination between behaviours. Humphrey's view is thus a maturationist view in strong contrast to that of White.

The observations of neonatal reaching (Bower, Broughton and Moore 1970; Trevarthen 1974; DiFranco, Muir and Dodwell 1978) led Bower (1974a) to propose that with environmental enrichment the 'silent' period between neonatal and visually guided reaching would disappear. Bower (1973) reported that such was the case. However, disagreement continued over the existence of neonatal reaching. Other researchers (Ruff and Halton 1978) using more rigorous criteria than Bower et al. (1970),and McDonnell (1979) concluded that conflicting results were the consequence of different procedures and criteria. Rader and Stern (1982) pointed out the importance of having a blank field control condition in studies purporting to show neonatal directed reaching. Using such a procedure they found strong evidence for the phenomenon. There is also evidence that such activity is related to active looking by the infant (von Hofsten 1982) at the object. Reviewing the literature on reaching (Johansson, von Hofsten and Jansson 1980) express this reaching phenomenon in guarded terms : '*...neonates*

> *seem to show some visually directed intentional movements towards objects*'

The transition from visually elicited to visually guided reaching is qualitatively very important. The infant needs to attend to the hand as it moves through the visual field to the position of the object. Such reaching requires proper sequencing of the component parts of the act (Bruner and Koslowski 1972) e.g. arm extension and flexion and anticipatory hand opening. Bruner proposed that in the context of his theory reviewed earlier (Bruner 1970) inhibition of certain elements in the sequence and/or re-arrangement of their order must be accomplished. The onset of visually guided reaching has been observed experimentally using prismatic glasses which visually displace the object laterally. McDonnell (1975) showed that prior to around 4 months infants were incapable of guiding their hand to the visually displaced position of the object. Using mirrors to visually displace the object, Lasky (1977) demonstrated a similar transition. Thus reaching prior to this was characterised as visually elicited or 'ballistic'. The infant's eyes are fixed on the object on the approach (von Hofsten 1979). Thus it seems likely that 4 month old infants use exclusively articular proprioception to localize the hand in space.

Remarkable observations of infants reaching for moving objects have been made recently (von Hofsten and Lindhagen 1979). At 18 weeks infants were able to catch an object moving at 30 cm/sec. The mutual interdependence of of eye and hand demonstrated by these observations suggest an ability to forsee the future position of an object.

The distinction between elicited and guided movement is one example of a neuropsychological trend in other domains of behaviour reviewed in the next section. This trend concerns the takeover of elicited motor systems by more adaptable and voluntary systems of control mediated by the cortex.

2.2. Neurospychological Development and Spatial Behaviour

In reviewing the research on voluntary control of reaching a distinction between 'proximal' and 'distal' components has been drawn (Johansson, von Hofsten and Johansson 1980; Lockman and Ashmead 1983). As a general principle of sensori-motor organisation, this distinction can be observed in the peripheral and foveal visual systems (Trevarthen 1968; Prablanc and Jeannerod 1975). At the level of reaching behaviour, proximal reaching involves the muscles of the shoulder arm and hand whereas distal activity involves the smaller muscles of the hand, digits and (perhaps) the wrist. This functional distinction is based on observations of both immature primates and mature primates who have sustained damage to central nervous system structures involved in distal movements and on behavioural and neuroanatomical comparisons across mammalian species (Brinkman and Kuypers 1972, Haaxma and Kuypers 1974, Kuypers 1962, 1973, Lawrence and Hopkins 1972 and Lemon 1981). Haaxma and Kuypers (1974) found that rhesus monkeys with lesions designed to interfere with visuomotor coordination of distal motor behaviour were able to move their hand to a well containing food but did not make fine adjustments of the hand and fingers in order to retrieve the food.

The proximal motor system is mainly organised at the brainstem level while the distal system is primarily cortically organised. At the neuro-physiological level these functions are mediated by the extrapyramidal and pyramidal tracts respectively (Walshe 1948). The pyramidal tract, runs uninterupted from the sensorimotor cortex to the spinal cord. A major function of this tract is to integrate motor activity with detailed sensory information from various modalities (Henneman 1974). It is responsible for the fine motor adjustments such as precision grasps characteristic of high level reaching.. The extrapyramidal tract requires careful definition as it is a somewhat diffuse collection of fibres. It is defined by Walshe (1948) as:

efferent cortical neurone systems other than the pyramidal and also to all subcortical efferent neurone systems that subserve movement'

The extrapyramidal tract is responsible for the ballistic flinging of the arm to the target characteristic of early infant reaching.

Of importance here is the finding that in the rhesus monkey, the extrapyramidal tract develops earlier than the pyramidal tract (Kuypers 1962, Lawrence and Hopkins 1972). This developmental delay has an inevitable behavioural correlation (Lawrence and Hopkins 1972). In the rhesus monkey there is a comparable delay in the appearance of the distal components of reaching. This correlation corresponds to the findings noted earlier in the human infant (Lasky 1977; bower 1976; McDonnell 1975) that the distal components of reaching appear later than the proximal componenets.

Within the more specific tasks of detour reaching we are concerned with here, the work of Moll and Kuypers (1977) provides evidence of the neural processes involved. Adult rhesus monkeys were commissurectomised to enable within subject comparison of the behavioural effects of left or right unilateral ablations on individual animals. Subsequently, unilateral ablations of the pre-motor cortex, the supplementary motor cortex and the arcurate gyrus were made. These animals were then tested on a detour problem. They proved unable to circumvent a transparent barrier to retrieve a visible food reward using the hand contralateral to the ablated hemisphere. Instead the monkeys reached straight to the visible locus of the food and scrabbled ineffectively at the barrier. The same monkeys were able to solve the detour problem with the hand contralateral to the intact cortex.

This behaviour shows a marked similarity to that of young human infants without any such ablations (Bruner 1970). The deficit in the monkeys was thought to reflect the different roles of sub-cortical and cortical mechanisms in guiding the hand to the visual target. A subcortical control process mediated by the extrapyramidal tract may have the function of guiding the hand directly along the line-of-sight (proximal). On the other hand, a cortical mechanism mediated by the pyramidal tract may be responsible for fine motor control (distal) of flexing the wrist to circumvent the barrier. The cortical mechanism may also be responsible for coding the spatial and temporal relations involved in the detour movement.

It must be stated that the research on non-human primates must be viewed with care as some neural processes may be species-specific. Also the advocacy of a neuro-psychological view of the development of the spatial behaviour investigated in this thesis does not imply a reductionist view of development. The development of prehensile visuomotor co-ordination does not simply reflect the maturation of specific brain structures. The process of 'canalization' (Fishbein 1976, Wilson 1978) appears to encompass normal development best. In this process the genetic system is programmed to interact with normal environmental events for a given genotype and its ecological niche. Neurological structures mature in a given sequence and reach a particular endpoint. The environment, both internal and external, acts to 'channel' genetically programmed development in the correct direction for the species. As Gibson (1981) stated:

> *'The time has come to cease asking whether genes or environment are essential to the development of a particular behaviour and to start asking what is the nature of the genetic and environmental interactions which occur; what specific environmental stimuli are required at any point in time, and what latitude of environmental variation is compatible with normal development.'*

Thus neuro-psychological factors may be seen as facilitating the development of more complex instrumental actions. To this extent the takeover of the reaching system under voluntary control mediated by the cortex would appear to be under way by 5 months of age in the human infant. That this process might continue until the end of the first year when detours are solved is an empirical question which remains unanswered. Such a hypothesis must be considered though in the light of Moll and Kuypers findings with monkeys.

2.3. Motivation and Temperament

Most researchers in the area of detour problems have mentioned the motivational state of their subjects. The early work of Kohler (1927) and Lewin (1934, 1936, 1947) indicated that a highly valued goal object which induces an over-excited motivational state may inhibit indirect problem solving. Thus Kohler (1927) reported such behaviour by a dog. Placed in a 'U' shaped enclosure with a goal object of food placed just outside;

> *'(the dog) stood, seemingly helpless, as if the nearness of the object and her concentration upon it (brought about by her sense of smell) blocked the 'idea' of the wide circle round the fence.'*

Lewin (1934) similarly indicated that where a goal object is highly valued (high positive valence) this may inhibit detour performance. The relationship between performance on tasks and motivational state may reflect the inverted 'U' found in discrimination learning. It has been usual for experimenters in infant cognitive development to report high levels of motivation in their subjects. Uninterested (low motivation) and distressed infants are usually excluded or tested again under more optimal conditions (Bruner 1970, Lockman 1980).

McGraw (1942) specifically examined the success of infant subjects who showed negative affect by crying at some stage in 3 different detour tasks. 'Cryers' still showed success on detour tasks (10 out of 23, 14 out of 21 and 2 out of 12 cryers on the 3 tasks), with the most deletereous effect on the most difficult task.

Kramer and Rosenblum (1970) investigated the relationship between affect, effort, span of interest and success on a detour-reaching task. The 12 month old subjects were categorised into 3 groups.

1). 'Winners' were characterised by success at the task, positive or neutral affect, sustained interest and a relative absence of breaks of interest.

2).'Shifters' demonstrated shifts of interest to other foci of interest in the test room, positive or neutral affect but no success on the task.

3). 'Criers' showed negative affect, rapid drop in interest with shorter spells of interest than the other groups and no success at the task.

The criers' loss of interest was preceded by negative affect and hence indicates a low frustration tolerance whilst the 'shifters' maintained attention at a similar level to the 'winners'. Test results appear to contradict McGraw (1942), who found a considerable level of success in subjects who showed negative affect. Different age ranges studied may have accounted for this anomaly . Kramer and Rosenblum did find that success at the detour task did not relate to level of development on the Gessell Developmental Schedule (Gessell and Amatruda 1947).

It is not possible to determine from these studies whether a better performance was possible by infants who failed ('shifters' and 'criers'). It can be concluded though, that frustration can be controlled by some subjects by a shift in interest. There is though a distinction between short-term gaze aversion and reversion and the termination of interest. Kaye (1970) found that the behaviour of 6 month old infants who looked away from the task were consistent with Schneirla's (1959; 1965) interpretation of the approach-avoidance conflict. On this view, avoidance results from a too high level of stimulation. Combined with looking back at the task this maintains stimulation within a reasonably adaptive range. Kaye (1980) also noted that his subjects showed less looking away when the mother was allowed to try to teach the child. In the instructional situation, Kaye found that looking away functioned as a signal for the mother to intervene.

In summary, studies of motivation and temperament indicate individual differences are found when studying infant temperament. No concrete evidence has to date been found that infant performance on detour tasks is affected by temperament. The evidence suggests that on the contrary failure may lead to distress or distraction. It is clear though, that to optimise performance on infant cognitive tasks requires the researcher to make the infant secure and to ensure a high level of arousal.

2.4. Task Variables and Empirical Questions

The previous sections indicate that many different factors are brought to bear on a simple detour problem. These include perception, motor skill in different systems, cognitive level, neural development and temperament and motivation. In this section some of those factors potentially open to experimental investigation are examined.

2.4.1. A Possible Mechanism for the Origins of Detour Problem Solving

Chapter 1 and the previous sections indicate that many different factors are brought to bear on a simple detour problem. Perception, motor skill in different systems, cognitive level, neuro-psychological development and temperament and motivation. The approach adopted in this thesis is primarily a structural one emphasising the Piagetian account of cognitive development and the related construction of reversible and associative operations investigated by Lockman (1980). The Piagetian account though may underestimate the infant's perceptual competences. Many studies have indicated early pre-adapted substrates for later development (reviewed earlier). Of particular importance are the availability of perceptual mechanisms for constructing the object concept (Bower 1974a; Butterworth 1981) and other crucial developments in postural development (Butterworth and Hicks 1977), joint visual attention (Butterworth and Hicks 1980; Butterworth and Jarrett 1981) etc. Such perceptual mechanisms may play an important role in the origins of detour problem solving. Of possible importance to the detour task are the perceptual mechanisms of motion parallax and the potential displacements of the eyes and head to reverse occlusions.

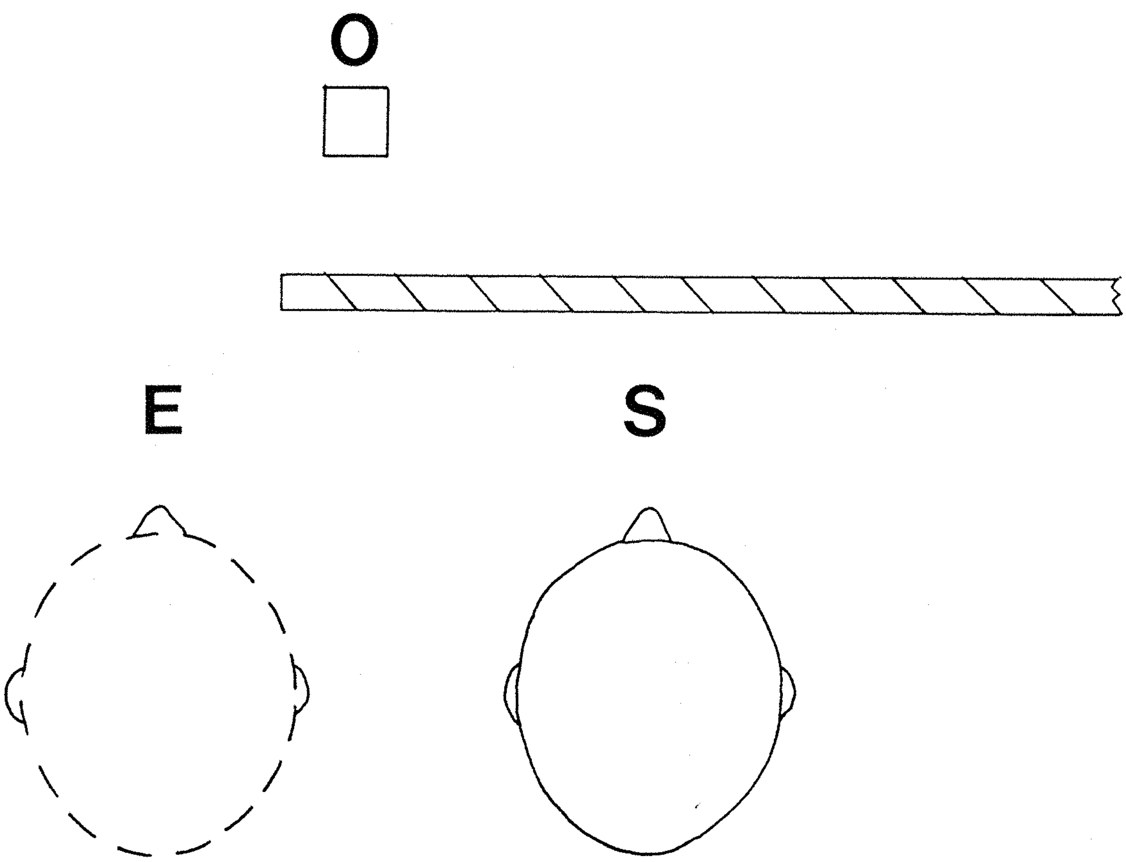
These are particularly interesting because Piaget's account of spatial development places such a high value on the role of self produced motion. Piaget describes movements of the eyes and head prior to independent locomotion in great detail. The infant's interest in changes in perspective during stage IV are well documented (Piaget 1954). However for Piaget (reviewed in chapter 1) it is principally by actively exploring space manually and through locomotion that spatial understanding and skill develops.

A brief consideration of the transparent screen detour problem shows that a mechanism like motion parallax may supply information to the immobile infant which would potentially construct the necessary displacements for the solution of a detour problem. An infant facing a transparent barrier with an object behind it will by the movement of her head generate motion parallax between the object and the edge the barrier. The displacement of the head towards the edge of the barrier will reduce the perceived distance between the edge of the barrier and the object. Under certain spatial conditions (see Figure 2.1.) the infant's displacement of herself may remove the barrier as an obstruction to the action of the infant.

In contrast, the reports of such displacements with opaque barriers (Bruner et al. 1968) would imply the development of associativity. No motion parallax is generated when an object is entirely occluded. Lockman's analysis (Lockman 1980) of this problem with opaque screens is the same. To remove an opaque screen from in front of an object requires the stage IV aquisition of reversing the occlusion. In contrast going around the screen requires some form of internal spatial representation and the associative group of displacements. Reported observations of infants reaching around opaque vertical screens (Bower 1975) during Piaget's stage III were not replicated by Lockman (1980. He found that detours were only solved after progression to stage IV and possibly later. The opaque barrier detours were however solved prior to stage VI, contrary to prediction.

If the perceptual mechanism were available for transparent detour problems, having made the reversible displacement to the edge of the screen the infant would now be in a position to reach directly along the line of sight to retrieve the object (see Figure 2.1.). Motion parallax cues are potentially available from the onset of postural head control. Thus the solution of transparent detour problems in manual space may be available to infants early in development.

Figure 2.1. Possible Solutions to a Detour Reaching Problem.



Note. The infant may solve this problem in two ways.

1. The infant at S may displace herself to E and then reach directly to O. This would be physically more difficult with a longer screen.

2. The infant may remain at S, displace her hand from S to E and then reach in to O.

With a transparent screen motion parallax is generated between E and O when the subject moves towards E. With an opaque screen no such perceptual cues are immediately available.

Piaget did not discuss manual detour problems. However the mechanism proposed would appear to be a Stage IV reversible action. Similar types of reversible actions are discussed in chapter 1.

It is possible that such a hypothetical displacement of self mechanism may be involved in the construction of associativity. From the available evidence the consistent and immediate demonstration of detour problem solving with transparent barriers occurs late in the first year and early in the second year of life (Bruner 1970; Lockman 1984). This is consistent with Piaget's theory that associativity in visible detours develops during stage V. It is proposed that where early detour solving (during stage IV) occurs that the mechanism described here may well explain any discrepancies (these were noted in chapter 1.)

The questions raised by this section may be summarised thus:

1. Do infants solve visible detours prior to the development of associative groups in stage V (roughly 12-18 months)?
2. If so, are such infants in Piaget's stage IV solving visible detours by the displacement of self followed by a direct reach?
3. Are new solutions to problems such as the detour derived from earlier constructions such as reversible actions. Alternatively, do they appear by maturation or under voluntary control from a development of earlier visually elicited responses?

2.4.2. Spatial Variables in Detour Problems

In visible detour problems, there can be identified spatial relationships between the infant, the goal object and the barrier. These exist within a 3 dimensional space and can hence vary within 3 dimensions. Previous studies on infants (Bruner 1970; Lockman 1984) have varied lateral displacements of the barrier and object relative to the child. The depth of displacement behind the screen, and displacements in the vertical plane have not been systematically varied although McGraw (1942) reported some observations on this.

Bruner (1970) reported that his subjects evidenced a developmental trend which showed that the behavioural space within which the infant operates expands with age. The behavioural space he investigated was lateral space within the confines of detour ability. As discussed above, this may not be the case since detour studies with midline barriers may be solved by displacing the self to render the problem solvable by direct means. In such a case the infant has still solved the problem. He has not however shown the de-centred manual skill which indicates an understanding of manual (Euclidean) space. If such a solution were found the infant might be said to have a fuller spatial understanding evidenced by the eye-head-posture co-ordination than was shown manually. This gives rise to two questions:

1. Do infants show an expanding behavioural space in the visible detour problem?
2. Do infants show a developmental lag between different motor systems. Specifically can the group properties (rules of spatial behaviour) be demonstrated in the manual system prior to the locomotor system?

2.4.3. Scale of the Detour Problem and Development

Visible detour problems in human infants have been investigated in both reaching and locomotor spaces (Bruner 1970, Lockman 1984, McKenzie and Bigelow 1986). Only Lockman has to date compared the relative development of behaviour in reaching and locomotor spaces. A fundamental question is directed by such research. If the detour problem can only be solved by a particular form of internalised spatial representation, does that representation extend immediately to enable problems to be solved in all types of space? From Piaget's own observations we cannot draw any direct conclusion. However, Piaget does indicate that a distinction between 'near' and 'not-so near' space exists prior to the arrival of independent locomotion (Piaget 1954). During stage 3 (4-8 months) Piaget characterises this as follows:

> *'....the objects grasped are regulated in depth in relation to the body itself; distant space merely*

appears then as a kind of neutral zone in which prehension is not yet ventured.' (Piaget 1954 obs. 97.)

This distinction begins to end during stage 4. The perception of depth is extended outwards beyond the area defined by manual activity:

'At 0:11(7) Jaqueline is seated on a sofa. I make an object disappear under the sofa; she bends over to see it. This action shows that for her the vanished object is located on a plane deeper than that of the edge of the sofa, the latter plane itself belonging to distant space (inaccesible to prehension).' (Piaget 1954 obs. 97.)

It follows that detour reaching should precede locomotor success on structurally similar tasks. The infant inevitably has more experience in reaching space than locomotor space. Further it is possible that larger scale spaces require more of the detour space to be represented.

Lockman (1984) found that in both opaque and transparent barrier problems the majority of infants solved the reaching problem before the crawling problem. None of Lockman's subjects solved the crawling problem before the reaching problem although some solved both tasks in the same testing session. The average time lag for transparent barriers was 4 weeks and for opaque barriers was 6 weeks. This certainly provides strong evidence for the experience hypothesis which can be generated from Piagetian theory. However there are structural differences beween small and large scale problems. The reaching space problem may in some instances be resolved by displacement of the head (and trunk) resolving it into a line-of-sight problem. The larger scale problem can be seen in this way as well. However, the infant must move along the detour path from the beginning to generate motion parallax and the reduction between the barrier edge and the object.

It is possible that the reported differential performance between reaching and locomotor space might be accounted for on a representation hypothesis. The amount of detour space to be represented in a locomotor space may be greater than in a reaching space. Further Lewin (1936, 1947) hypothesised that as the angular discrepancy between the required initial detour path and the direct path to the object increased, so would the infant's difficulty with the problem. This hypothesis was tested by Lockman (1984) in 2 longitudinal studies of detours in a locomotor space. In the case of opaque screens the width of the screen and hence the amount of space to represent was varied. In the case of transparent screens, the spatial relationship between the infant the barrier and the screen was varied. In none of these conditions was there any difference in the ultimate success of the subjects. The angle between the detour path and the direct path to the object was varied up to 90°. However no conclusions can be drawn from these results for angular paths greater than 90°.

In their study, McKenzie and Bigelow (1986) found a significant increase in efficiency in solving locomotor detour problems with age. The researchers investigated 10, 12 and 14 month old subjects who could solve the detour problem and excluded those who could not. The results of this study showed a marked increase in efficiency of route with age. Efficiency was measured by the ratio:

$$\frac{\text{distance reduction in terms of route to the goal object}}{\text{overall distance moved} \times \text{the distance reduction.}}$$

Route efficiency in 10 and 12 month old infants was disrupted when the screen was moved from left to right (or vice-versa). This was consistent with results showing perseveration in 2 choice maze tasks (Heth and Cornell 1980). Infants' performance continued to be disrupted in situations where the path to the object altered, until they reached 14-15 months of age. McKenzie and Bigelow (1986) mention that in their task:

> *'...younger infants crawled staight ahead toward the barrier, and using it as a support, walked along its length to the opening.'*

They further suggest that infants lacking experience of independent locomotion may require more attention to be used to practice this skill. This would inevitably leave less attention for the spatial aspects of the problem. This untested hypothesis is distinct from the experiential hypothesis. Inefficiency in detour problems may arise from inadeqate spatial skill derived from practice. It may also arise from lack of available information processing capacity. In all studies of detour problem solving to date these hypotheses are confounded.

In contrast to Lockmans' results in locomotor space, in reaching space, Bruner (1970) found significant differences when spatial changes were made in the relationship between object, barrier and infant. These differences have been discussed earlier. Bruner also found, as did McKenzie and Bigelow (1986) that a left to right change in barrier position disrupted younger infant's performance. It must also be noted that Lockman tested infants in their own homes and this familiar environment may have given the infant specific landmarks as cues to action. In contrast McKenzie and Bigelow tested infants in the laboratory as did Bruner. This uncontrolled variable may be important in locomotor tasks, and could account for the lack of any effects on behaviour by Lockmans' spatial variables. Home environment may be less important in reaching studies, where the space in which infants are being tested is defined by the apparatus. However, Acredolo (1979) found that the home environment affected performance on a stage IV task by influencing the choice of egocentric or allocentric spatial reference code. It is possible that even in reaching studies familiar landmarks may give guidance to the unskilled infant.

In summary, three questions are of interest concerning the relationship between type of space and transparent detour problems:

1. Does the reported delay in solving locomotor over reaching detour problems reflect different task specific variables inherent in the scale of the task (e.g. the availability of a displacement of self 'leaning' strategy)?
2. Does ability at manual detour problems generalise to larger scale problems and with larger angular disparities between direct and detour paths than those yet tested?
3. What are the effects of experience of the different motor systems and training on success at detour problems?

2.5. Summary

1. The relationship between spatial development and the specific motor skills of reaching and locomotion were reviewed.

2. The distinction between proximal and distal components of motor skill were described. The proximal components of reaching involve the gross movements of the arm and shoulder to a target. The distal components involve finer movements such as manipulatory hand movements. The neurological substrate for this sepqration distinguished between the pyramidal and extrapyramidal pathways and their relationship to instrumental responding.

3. The work of Moll and Kuypers (1977) on rhesus monkeys suggested that cortical mediation of distal components may be necessary for the voluntary control of spatially complex behaviour. This may also be necessary to inhibit direct reaching.

4. Aspects of motivation and temperament were reviewed with respect to specific studies of detour problem solving in human infants.

5. The empirical questions addressed in this thesis were listed. These centred on the possibility of the origins of detour problem solving in reversible operations derived from perceptual mechanisms. The availability of a displacement of self mechanism constituting a resolution a detour problem into a direct line-of-sight problem was suggested. The questions also addressed the generalisation of detour problem solving across different spatial arrangements and reaching and locomotor spaces.

CHAPTER THREE.

EXPERIMENT 1: DETOUR REACHING IN 8-10 AND 16-18 MONTH GROUPS.

3.1. Introduction

In this chapter an experiment is described which compares the performance of 8-10 month infants with 16-18 month infants on a transparent barrier detour problem. All infants were tested on a test of progression to Stage IV, the ability to search for a hidden object. The experiment also evaluates the nature of perseverative errors in infant search in a detour space.

Search for a hidden object may be seen as proof of the comprehension of relationships 'behind', 'in' or 'under'. Bower (1974a) reported results which indicate that 'in' is understood after 'behind' or 'under'. He pointed out that an object going behind another is in a different spatial location from the occluding cover or screen. However an object inside another is in the same place. Thus a more parsimonious test of under is to use a cloth cover which also occupies the same space as the hidden object. However the cover may only be perceived as a 'sign' of the presence of the hidden object (Piaget 1954). It would seem that the understanding of 'behind' is incomplete if the infant cannot go behind a barrier by a detour route. The comparison between search for a hidden object and the detour test in this experiment should assist in elucidating this developmental sequence.

Previous studies of infant performance on transparent detour tasks in manual space (Bruner 1970, Lockman 1984) have raised questions of task performance using different spatial arrays and age or developmental level. Bruner (1970) found specific trends in characteristic behaviour by infants, from a predominant strategy of line-of-sight reaching at 6-9 months to immediate success by most 14-17 month old infants. However a number of young infants in the 6-9 month group achieved success on the task. Lockman's subjects (Lockman 1984) succeeded at a mean age of 10.79 months,ranging from 8-12.36 months in his longitudinal study.

Bruner, Kaye and Lyons (1968) noted that for detour tasks with opaque screens, infants would lean around the barrier to see the object. It is possible that Stage IV infants might also be able to solve transparent detour problems by such a strategy. In terms of Piaget's theory such a solution to the problem might be available prior to development of associativity during stage 5. Piaget noted that his daughter, Jaqueline was capable of similar actions to that required for a displacement of self or 'leaning' strategy during Stage IV at the age of 11 months (Piaget 1954).

In order to evaluate detour knowledge this particular solution is excluded here by the design of the apparatus. With the detour path displaced away from the infant's midline and the path being through a hole at hand height such a displacement of self was not likely and in practice not observed.

Bruner (1970) showed that 6-9 month old infants found detours with screens placed with the edge at the midline were easier than those with screens extending across the midline. His conclusion that behavioural space expands with age may, however, be incorrect. Leaning around the screen would be physically easier with the screen edge at the midline. This may account at least in part for the difference in ease of tasks with midline and peripheral screens. The apparatus used in this study also excludes some of the problems experienced by Bruner's subjects. Many infants in Bruner's study used their contralateral hand to attempt the required detour movement. This was because in some conditions the required detour path was on the opposite side to the goal object. By placing the object and the required detour route on the same side of the infant, the hand ipsilateral to the object (usually initiated first by young infants), is always the correct hand to solve the detour.

Bruner et al. (1968) reported that in a detour test with a transparent screen, some infants made perseverative resposes when the screen and object were switched from left to right (or vice-versa). Butterworth (1977) reported that 8-10 month old infants made perseverative errors in Piaget's Stage IV object permanence task (see Chapter 1) even when the object was entirely visible. The object was first placed at a position A, left (or right) of the infant and then covered. The infant was allowed to retrieve the object. It was then placed at a different position B on the right (or left) of the infant. A proportion of infants removed the cover and searched at location A even though they had seen the object moved to location B. However, such errors did not occur unless the object was covered with a transparent cover. An uncovered object resulted in statistically correct search in this age group. Importantly, Butterworth noted that with the object covered and hidden, or covered and visible the proportion of infants erring did not show statistically incorrect search on B trials. Longitudinal studies of the object concept have confirmed the existence of this equiprobable pattern of search in the Stage IV task (Bower and Patterson 1973; Gratch and Landers 1971). Butterworth proposed that this divided pattern of search was due to a conflict between two spatial codes potentially available to the infant. The egocentric code (Paillard 1974) locates the object relative to the self. The failure to update the egocentric code when the object is moved to B is in Piaget's view (Piaget 1954) responsible for the search error. However the allocentric code (Merleau-Ponty 1962) may specify the position of an object in relation to a landmark or background (Bremner 1978; Butterworth, Jarrett and Hicks 1982). In Butterworth's view, the conflict between the out of date egocentric coding and the allocentric coding of the object at B gives rise to the divided search pattern. Further Butterworth proposed that the developmental problem in Stage IV may not be that defined by Piaget (1954) of arriving at a rule which states that an object retains its own identity over a change in position. Rather, on this view, the problem is that of co-ordinating the conflicting frames of reference (Butterworth 1977).

The generation of search errors at a visibly empty place appears to rule out common explanations of the Stage IV error which implicate memory (Harris 1973; Gratch, Appel, Evans, Le Compte and Wright 1974; Bjork and Cummings 1984). By comparing search errors when the object is visible but unscreened and visible but screened, the nature of search errors may be investigated in detour spaces. It is hypothesised that for Stage IV infants, following search at location A, search errors will occur when the object is located at B. Accessing a detour space requires some form of spatial representation and hence the identical conditions described by Butterworth (1977) would pertain. The object would be identified according to an allocentric code whilst the screen and hence detour path would be located by an egocentric code. When the object is at A, the codes coincide. However when the object is moved to B, the egocentric code conflicts with the updated allocentric code and a divided pattern of search across subjects is hypothesised. For the condition where the object is directly available (uncovered), i.e. where line of sight and line of reach coincide, object identification and retrieval can both take place using simply the allocentric code at B as well as A. The retrieval of the object on the A trial is not an essential to the generation of search errors at B. Under certain conditions the sight of the object at A may be sufficient to generate errors at B (Butterworth 1974).

The experiment thus had three aims. First to investigate the performance of infants on a detour reaching task. It was hypothesised that with the elimination of leaning actions around the screen, 8-10 month old infants would fail to solve the detour whilst 16-18 month infants, having advanced to stage V would show the required manual detour reach. A second aim was to compare performance on the detour test with a test of search for a hidden object. Infants who can retrieve a hidden object do not necessarily have a complete understanding of under or behind. Such an understanding of the relationship would require the ability to detour around to get behind (or under). A third aim was to test for perseverative errors in infant search in a detour space. It was hypothesised that stage IV infants would show perseverative errors in search in the Indirect condition whilst older infants would search accurately.

3.2. Method

Subjects

48 infants served as subjects. These were divided equally into younger and older age groups. The younger subjects were divided equally into sub-groups which were 8, 9 and 10 months old and the older subjects into subgroups 16, 17 and 18 month old.

Younger group:

8 month olds (4 boys; 4 girls) whose mean age was 262.1 days S.D. 8.8 days (range 247-272 days).

9 month olds (4 boys; 4 girls) whose mean age was 288.8 days S.D. 9.7 days (range 276-302 days).

10 month olds (4 boys; 4 girls) whose mean age was 322.5 days S.D. 10.3 days (range 307-334 days).

Older group:

16 month olds (4 boys; 4 girls) whose mean age was 1 year 135.6 days S.D. 7.7 days (range 1 year 124 days-1 year 142 days).

17 month olds (4 boys; 4 girls) whose mean age was 1 year 168.1 days S.D. 9.98 days (range 1 year 154 days-1 year 182 days).

18 month olds (4 boys; 4 girls) whose mean age was 1 year 199.3 days S.D. 10.0 days (range 1 year 184 days-1 year 211 days).

Four infants aged 250, 281, 307 and 311 days were excluded from the sample because they fussed and failed to complete the experiment. 2 of these infants failed the pre-test.

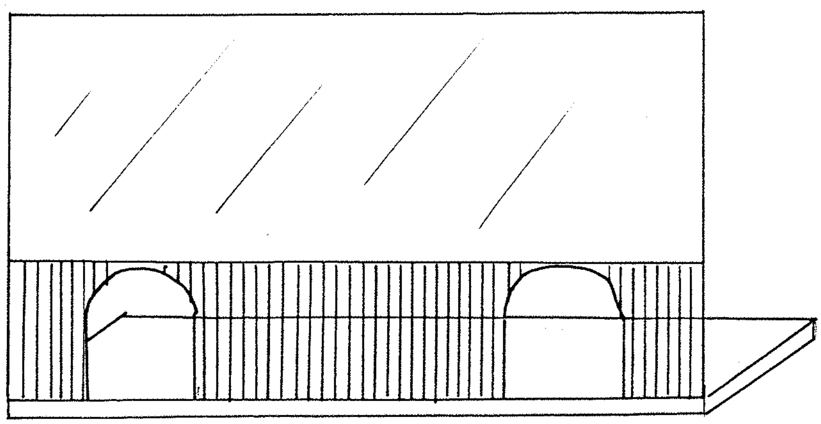


FIGURE 3.1.

Detour Test Apparatus used in Experiments 1,2 and 3

Apparatus

This comprised a low chair in which the infant was seated and strapped in for safety and a seperate moveable stand. For the pre-test a flat green baize table was placed on the stand and a small white cloth (18cm×14cm) was used to cover an object. The object was a bunch of keys or a small toy car if the keys proved unattractive to the infant.

For the detour test, a transparent screen (49cms. wide and 22cms. high) was mounted on the stand (see Figure 3.1). Two arch-shaped holes (10cms. wide and 8.5cms high) were cut at the base of the screen, 4.5 cms. in from the left and right edges of the screen. The centre of the holes was 15 cms. to the left and right of the midline. The outline of the holes was emphasised by black tape. This spatial arrangement was designed to preclude accidental success and leaning around the side of the screen. Vertical black stripes were applied to, the screen using letraset to a height of 11cms. This enabled the infant to see the screen clearly and also to see through it. Behind the screen was a shelf 12cms. deep covered in green baize. In the detour test the object to be retrieved was the same as in the pre-test.

Design and Procedure

Pre-test

All the infants were seen at their local health clinic or in the laboratory. The environment was always plain and the subject's visual field clear of extraneous objects. The infant usually attended with her mother who had volunteered for the experiment. The infant was sat in the low-chair facing the green baize table and strapped in for safety. While the infant was settled the experimenter aroused her interest in a toy (the object). The pre-test began with the object placed on the table which was out of the infants reach. While the infant watched, the object was covered with the white cloth. After 3 seconds, the platform was moved into the infants reach and she was allowed to search for the object. If the infant failed to remove the cover and retrieve the object within 15 seconds, the procedure was repeated with a different object. In a related study Lockman

(1984) used a test for Stage IV abilities derived from the Uzgiris-Hunt (1975) scales of infant development. Using a more rigorous procedure the infant was required to retrieve an object successively from under each of three covers. Lockman's hiding procedure aimed to control for the possibility that the infant might simply be lifting the cover because it was there and not to search for the hidden object. However, such a test is really a test of advance to Stage V since the infant in Stage IV would on Piaget's theory (Piaget 1954) fail to search correctly at the second and third hiding places. Thus the three cover test used by Lockman, is extremely conservative and the mean age of advance to Stage IV (around 9 months) he reported is consequently somewhat older than expected.

The procedure used here is a less conservative test of advance to Stage IV as defined by Piaget. Further, observation of infants in this study revealed that they were actively looking for the object and were not pre-occupied with the cover. This was clear when infants reached immediately for the object when the cover was removed.

Detour test

In the detour test, the screen was fitted to the stand and placed out of the infants reach. On each trial the object was placed on the platform either 3 cms. behind the hole (Direct condition) or 3 cms. behind the screen and 3 cms. to the side of the hole, toward the middle of the the screen (Indirect condition). After a delay of 3 seconds the screen was moved into the infant's reach and she was allowed to search. The delay was interposed because previous research had shown that perseverative errors in search were more frequent after such a delay (Gratch, Appel, Evans, Le Compte and Wright, 1974).

Each trial was terminated when the infant retrieved the object or after a period of 15 seconds. At the end of each trial the infant was shown the object to maintain her interest or if she had retrieved the toy it was recovered from her. Each infant received a block of 6 Direct and a block of 6 Indirect trials. The order was counter-balanced so that half the subjects received

Direct trials first and half Indirect trials first. Within each block of 6 trials, the first (A) trial was on the infant's left (or right) and the 5 (B) trials were at the other location (right or left). The side of the first A trial was counterbalanced. The transition from the Direct to Indirect (or vice-versa) block of trials was continued on the same side. Thus the A trial on the second block of trials was on the same side (left or right) as the 5 B trials in the first block.

The experiment was video-filmed from in front of the infant through the detour apparatus as near to the infants midline as the room permitted but no more than 25° from the midline. Although visible to the infant, the camera did not prove a significant distraction to the infant. The mother or other caregiver, who was always present, sat behind the infant and was instructed to give no assistance to the infant. The experimenter sat on the infants right.

Scoring

The video-film of each infant was carefully examined and the sequence of actions within each trial was recorded in categories pre-determined by examination of pilot data:

a. Success or Failure at retrieving the object.

b. Right or Left hand (either Ipsilateral or Contralateral) activated for each reach either to the position of object (right or left) or to the previous position of the object (left or right). A reach was recorded if the hand extended over half way from infant to screen.

c. Indirect (IR) or Direct reaches (DR). Indirect reaches were recorded if the reach was through a hole in the screen with a flexion of the hand at the wrist. Direct reaches were recorded if the reach was to the screen along the line of sight. Where it was possible to discern the nature of the Direct reach it was recorded as Pointing, Grasping.

d. Other reaches, clearly not directed at the object but at the Barrier (B) above the 11cms. line were recorded. Where possible, it was noted when these actions involved Grasping, Banging and Pulling the screen.

e. For perseverative reaches an error was recorded if the infant reached to the wrong side of the apparatus on their first attempt within a trial. This included both direct reaches or detour reaches for the Indirect condition. Thus retrieval of the object did not define correct or error but the side of the reach relative to the location of the object. It is usual to adopt a non-correction procedure between trials in Stage IV experiments but this was not done here. The central aim was to investigate detour problem solving and a trial length of 15 seconds gave infants an oppotunity to demonstrate their competence.

Inter-observer reliability

A second independent scorer viewed video-film of 10% (5) of the subjects to establish the reliability of the experimental data. For the basic categories of Success or Failure, agreement was reached on 59/60 trials (98%). For the all other measures, inter-scorer reliability was in excess of 95%.

3.3. Results

Examples of infant performance

Before giving the analysis of results there follows a description of some individual infant responses. Different responses at different ages are illustrated by the following 4 infants.

Subject 2.

A typical 8 month male infant shows the characteristic pattern of failure at the detour problem in this age group. Presented with the object in the Indirect condition and placed to his right he fixates it. He reaches out along the line of sight with the ipsilateral (right) hand and grasps at the screen. He brings in the contralateral (left) hand in a similar way at the same locus. Withdrawing both hands he now reaches out again at the screen and strokes it with both his palms. He then claws at it with his contralateral hand. His visual attention is now focussed on the screen rather than the object.

On his second trial, with the object now placed on his left he fixates the object but then checks back to his right (the previous location of the object). He reaches out along the line of sight with his ipsilateral (left) hand and grasps at the screen behind which the object is located. He now reaches out with the contralateral hand and claws at the screen moving his gaze to focus on this activity. On his fourth Indirect trial he grasps the top edge of the screen and pulls, as though trying to remove it. Later in his Direct trials he retrieves the object effortlessly. This infant showed no understanding of the possibility of using a Detour reach through the holes in the screen. He did however appeared to attempt to remove the screen which would be adaptive in other circumstances.

Subject 16.

An 8 month female infant receives the Direct trials first. She is successful in these trials, making anticipatory grasping motions with both hands before retrieving the object.On her first Indirect trial the object is placed on her left. She fixates it and reaches out along the line of sight. As her hand reaches the screen she points at the object and then claws at the screen.She looks away and then repeats the same response. On the next trial the object is placed on her right and she fixates it. However, she now reaches out with her contralateral (left) hand grasping at the previous location of the object on her left. Switching her gaze to the left hand, she now reaches out and grasps the right side of the screen but still ineffectually along the line of sight. On her third Indirect trial, after reaching out along the line she grasps the top edge of the screen with both hands and pulls at it.

This subject demonstrated a perseverative response on her first Indirect change trial. This was rare in this age group probably because of the failure to retrieve the object in the Indirect trials. Her initial act of pointing at the object on her first Indirect trial indicates an awareness of the futility of line of sight reaching in the detour task. Pointing did not occur in the Direct condition.

Subject 30.

A 17 month old male infant shows a more mature response to the detour task. He receives his Indirect trials first. On his first trial the object is placed on his right. He fixates it and both his hands reach out along the line of sight and point at the object. He withdraws his hands and immediately reaches through the right hole with his ipsilateral (right) hand, flexes his wrist and retrieves the object. On the next trial with the object now on his left he initially fixates it. Next he looks away to the right hole and brings in his contralateral (right) hand in an ineffective detour reach through the wrong hole. This is a complete repetition of his previously successful reach clearly a perseverative response. He now looks back to the object as he makes a line of sight reach with his ipsilateral hand terminating in a pointing gesture. He looks back to the right hole as both hands reach ineffectively through the right hole in a detour action. Finally both hands reach through their respective adjacent holes and the object is retrieved by his ipsilateral (left) hand. Later in Direct trials he shows no perseveration on change trials.

It is unlikely that infants have any experience of detour reaching hence the success achieved might be described as 'Insightful' in Kohler's use of the term. This infant's detour action appeared smooth and pre-planned, not a trial and error experiment by the infant. This subject though did make an initial reach terminated with a pointing gesture. The subject appears to know that pointing will not aid in recovering the object.

Subject 37

A 16 month old male showed that success was not guaranteed for older infants. He retrieved the object on the first reach of each of his Direct trials. On his first Indirect trial, his body and and gaze are oriented to the right at the location of the object. He reaches out with his contralateral (left) hand and points at the object. He repeats this and then turns away. Now he reaches out with his ipsilateral (right) hand and grasps the right edge of the screen but continues to fixate the object. He now places the flat of his left hand on the screen. He pulls the screen repeatedly and appears to be trying to move it but his visual attention remains firmly on the object. On subsequent trials he shows no attempt at reaching through the holes in the screen although he had done so to remove the object on Direct trials.

Pre-test

All the infants in both age groups were able to remove the cover and retrieve the hidden object on the pre-test.

First Response

The infant's first response to the first I trial is a measure of performance without any prior experience of the task. The most important measure of performance in this experiment is success but here responses were divided into 3 categories, Indirect (detour) Reach (IR), Direct Reach to the object (DR) and banging stroking or pulling the Barrier (B) (the screen). These results are showm in Table 3.1 and depicted graphically in Figure 3.2.

Table 3.1 Experiment 1

First Response of Infants in the Indirect Condition

Response Age	IR	DR	B	Total
8-10m	0 (0%)	21 (88%)	3 (13%)	24
16-18m	11*(46%)	11 (46%)	2 (8%)	24
Total	11	32	5	48

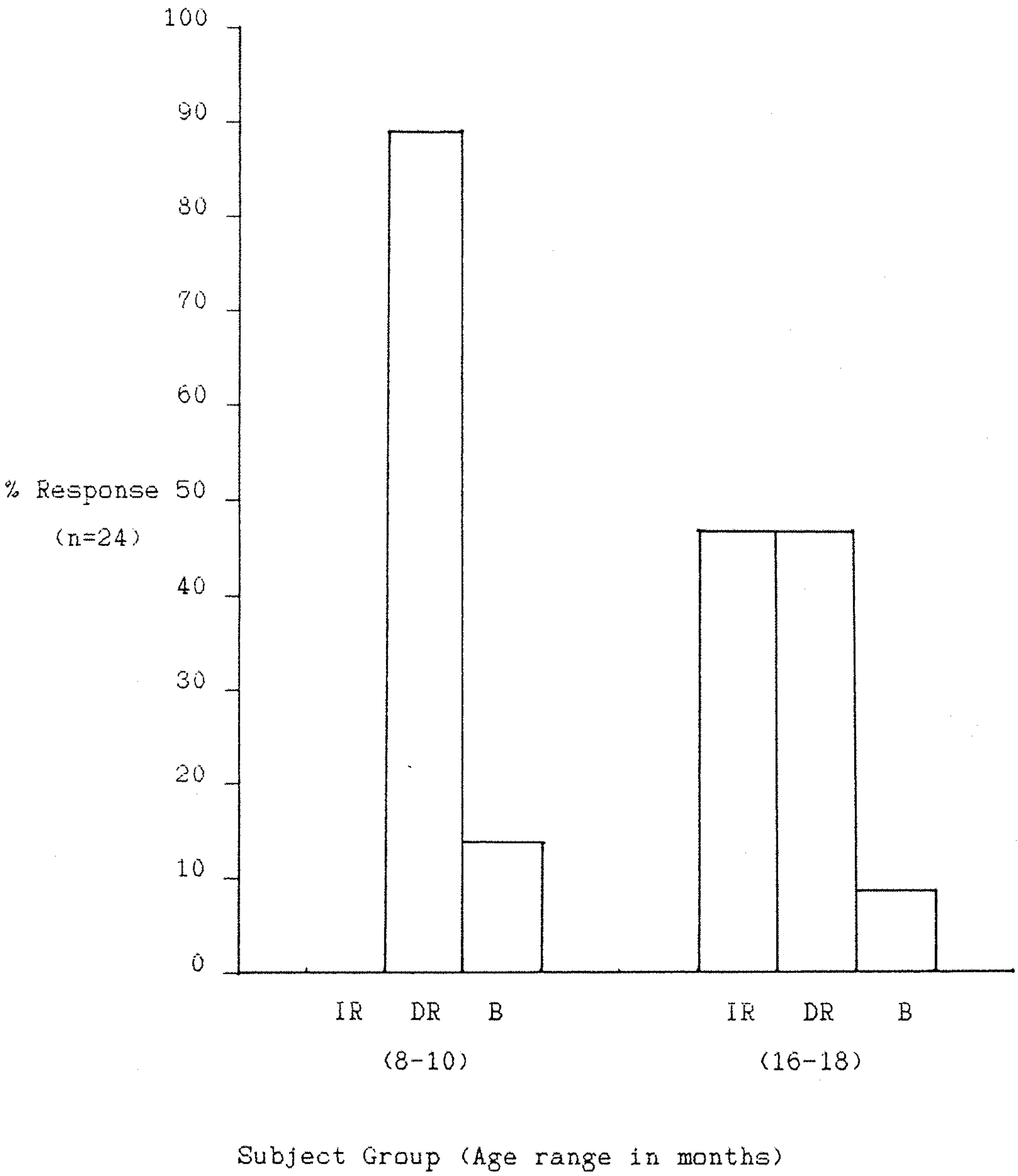
* This includes 2 infants in this group who performed an initially unsuccessful detour reach.

The characteristic direct reach to the object described earlier, predominated in the young group. Even in the older group 46% of infants showed this response. The comparison of indirect and direct reaches (excluding the B category because of low expected frequencies) showed the distribution changed across age groups (χ^2=14.10, 2df p<.001). This was due to the increase in indirect reaches and corresponding decrease in direct reaches with age. It was noted that banging, pulling and stroking the barrier was more common later in trials.

Figure 3.2. Experiment 1.

Graph Showing Infant's First Response on

Their First Indirect Trial (N=48)



IR Indirect reach

DR Direct reach

B Banging, Pulling and

Stroking the barrier

Successful Responses in the First Direct and Indirect Trial

The first trial for each condition provides a sensitive measure of immediate competence. By comparison success over 6 trials (given below) is more a measure of competence with a degree of practice. Success at the Direct reaching task was at ceiling level in both young and old age groups (see table 3.3). Only 1 infant in the young age group failed and none of the old group failed. There was thus no difference between Conditions (Fisher p=0.5 n.s.) or between age groups (Fisher p=0.5 n.s). This was expected since by 8 months normal infants have achieved a high level of direct reaching. Equally there were no effects of order (Fisher p=0.5, n.s.), sex (Fisher p=0.5, n.s.) or side, left or right (p=0.5, n.s.).

For the Indirect reaching task Table 3.2. shows that overall 20/48 infants succeeded on their first trial. However only 1 young infant succeeded compared with 19 old infants. A χ^2test showed the old infants to be significantly more successful than the young infants (χ^2=26.08, 1df p<.001). The small expected frequencies for age sub-groups made further analysis impossible.

It was possible that infants with experience of reaching through the holes in the apparatus might have an advantage in the Indirect task. 8/24 infants who performed the I condition first succeeded whilst 12/24 who performed the D condition first succeeded on the I condition. However the order of presentation of the tasks had no significant effect on performance in the I condition (χ^2=0.77, 1df n.s.). This accords with Bruner's finding (Bruner 1968) that shaping the task did not improve performance. Tests also showed no difference between sex (χ^2=0.77, 1df n.s.) or side, left or right (χ^2=0, 1df n.s.).

Using the McNemar χ^2 test, change in performance between I and D conditions compared:

a) The number who were successful on the Direct but failed the Indirect task, with

d) The number who were successful on the Indirect but failed the Direct task.

TABLE 3.2 Experiment 1

Number of Infants Successful on Their First Trial

Subjects (n)	Indirect Condition (I)		Direct Condition (D)	
(48)	20) (42%)		47 (98%)	
Order of Conditions				
(24)	I 1st	I 2nd	D 1st	D 2nd
	8	12	24	23
Age Groups				
	Young	Old	Young	Old
(24)	1	19	24	23
	(4%)	(79%)	(100%)	(96%)
Age within Group				
	8m 9m 10m	16m 17m 18m	8m 9m 10m	16m 17m 18m
(8)	0 0 1	5 7 7	7 8 8	8 8 8
Sex of Infant				
	Male	Female	Male	Female
(24)	8	12	23	24
Side				
	Left	Right	Left	Right
(24)	10	10	23	24

Overall there was a significant change across I and D conditions (a=28, d=0; χ^2=26.04, 1df p<.001). Comparisons between I and D conditions in age groups showed change for the young group (a=23, d=0; χ^2=21.04, 1df p<.001) and for the old group (a=5, d=0; p=.031 (binomial test used because of small expected frequencies)).

Performance Over the Six Direct and Indirect Trials

The mean success scores (out of 6) for Direct and Indirect trials are shown in Table 3.3. The success rates for Direct trials were at ceiling level for all age groups. A Student's 't' test showed a significant overall difference in performance between Direct and Indirect trials (t=9.07, df 47 p<.001). (Boneau (1960) has shown that the 't' test is little influenced by heterogeneity of variance when n_1=n_2 and hence transformation of the data was unecessary.) Inspection of Table 3.3 shows that performance on Direct trials was at a higher level than Indirect trials. Separate 't' tests on age groups showed that both (a) 8-10 month and (b) 16-18 month age groups performed significantly better on the Direct trials than on Indirect trials: (a) t=48.97, 23df p<.001; (b) t=4.52, 23df p<.001.

Analysis of Indirect trials showed that neither (a) sex or (b) side of starting contributed significantly to success: (a) male mean = 1.83, female mean = 2.79, t=1.20, 46df n.s.; (b) left mean = 2.17, right mean = 2.45, t=0.17, 46df n.s.

To further assess performance on Indirect trials an Analysis of Variance was computed using the success rate out of 6 as the dependent variable. The independent variables in the analysis were age (8, 9, 10, 16, 17, 18, months), and order of trials (D or I trials first). The data was transformed x'= $(x + 0.5)^{1/2}$ to render the bi-modal (Poisson) distribution of scores more variable for the analysis (Bartlett 1936).

The results of this analysis are shown in Table 3.4. The effect of Age was significant (F=18.37, df 5,36 p<.01). Post-hoc comparisons using Scheffé's procedure were performed. Comparison of young and old groups using the contrasts -1,-1,-1, +1,+1,+1, showed a significant effect (F=86.64, df 1,36 p<.001) (this was tested against F' = 5F as recommended by Kirk (1968)). Inspection of Table 3.3. shows that the old group performed significantly better than the young group.

TABLE 3.3. Experiment 1

Mean Score of Successful Retrieval of Object Out of 6 Trials

Subjects (n)	Indirect Condition (I)						Direct Condition (D)					
(48)	2.31						5.96					
Order of Conditions												
(24)	I 1st			I 2nd			D 1st			D 2nd		
	2.00			2.54			5.96			5.96		
Age Groups												
	Young			Old			Young			Old		
(24)	0.08			4.54			5.96			5.96		
Age within Group												
	8m	9m	10m	16m	17m	18m	8m	9m	10m	16m	17m	18m
(8)	0.00	0.00	0.25	3.63	5.38	4.63	5.88	6.00	6.00	6.00	5.88	6.00
(%)	(0)	(0)	(4)	(61)	(90)	(77)	(98)	(100)	(100)	(100)	(98)	(100)
Sex of Infant												
	Male			Female			Male			Female		
(24)	1.83			2.79			5.92			6.00		
Side of Starting												
	Left			Right			Left			Right		
(24)	2.38			2.25			5.96			5.96		

TABLE 3.4 Summary of Analysis of Variance Experiment 1

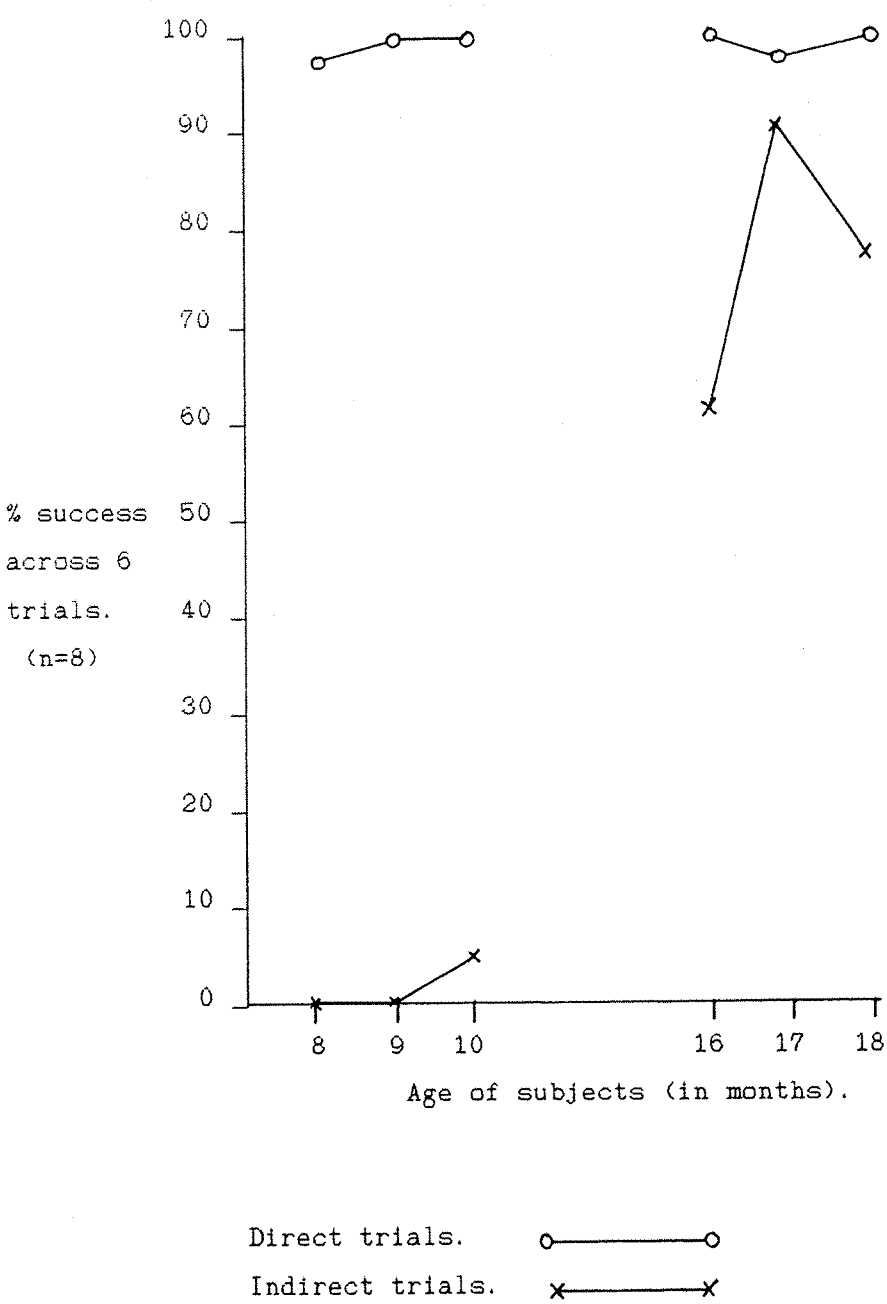
Source of Variance	Sum of Squares	d.f.	Mean Square	F Ratio	p
Order	0.49	1	0.49	1.81	n.s.
Age	24.80	5	4.96	18.37	<.001
Order×Age	0.28	5	.056	0.21	n.s.
Residual	9.67	36	0.27	-	-
Total	35.24	47	-	-	-

Comparisons between pairs of mean scores within the young and old groups, again tested against F' = 5F showed no significant differences in performance between age levels within young and old age groups: 8 vs 9 (F=0, df 1,36 n.s.), 8 vs 10 (F=0.18, df 1,36 n.s.) 9 vs 10 (F=0.18, df 1,36 n.s.), 16 vs 17 (F=4.81, df 1,36 n.s.), 16 vs 18 (F=5.19, df 1,36 n.s.) and 17 vs 18 (F=0.71, df 1,36 n.s.). These comparisons are depicted graphically in Figure 3.3.

As is clear from the table of mean scores, old subjects performed significantly better than young subjects. No transitions were found in the performance within young or old groups however. Hence although there is an apparent improvement in ability at the detour task between 16 and 17 months and between 16 and 18 months, this improvement was not significant. Thus it can be concluded that any transitions in performance on the detour task occur between 11 and 16 months of age.

Figure 3.3. Experiment 1

Graph Showing % Success in Indirect and Direct Conditions



As no order effect was found, it can be concluded that practice on the Direct task did not affect performance on the Indirect task. In the young group of subjects, it could not be argued that failure at the Indirect task was because the infants were unaware of the holes in the apparatus. To retrieve the object on Direct trials the infant had to reach through the hole in the screen. This clearly did not assist infants who had Direct trials first.

Perseverative Errors

The experiment was designed to compare perseveration in Direct and Indirect trials. The change in location of the object from left to right (or vice-versa) between trials 1 and 2 and trials 7 and 8 allows a comparison of the location of reaching activity caused by the change in location of the object. Bruner et al. (1968) noted a tendency for infants to continue using the same (but now inappropriate) hand when the location of the barrier opening was moved from left to right (or vice-versa). It is not possible to determine from Bruner's experiment whether reaches were also to the previous location. Physically changing the side of the barrier totally changes the space the infant is reaching in.

Perseveration on the first B trial

The results here are difficult to compare with other studies on the Stage IV error for two reasons. First, inspection of Tables 3.1 and 3.2 reveals that infants in the young group were unsuccessful at detour reaching. Indeed on the relevant A and B trial success at retrieval within the trial was: young group A=1, B=0 ; old group A=19, B=19.

Piaget's finding that infants in Stage IV perseverate to the original location of search was explained by the infant's belief that the act of retrieval reconstucted the object (Piaget 1953). Indeed even for a proportion of the old group, success over the trial was not forthcoming. Hence age of infant was confounded with success at detour reaching and hence comparisons of perseverative errors between age groups are similarly confounded. However experiments on the Stage IV error have generated errors when the object was not retrieved at A (Butterworth 1974; Bremner 1978).

Second, it is usual to adopt a non-correction procedure in such experiments (e.g. Bremner and Bryant 1977; Butterworth 1977). As this experiment assessed performance on the detour task over a 15 sec. trial and across 6 trials, the non-correction procedure was not used. Thus in analysing the errors in search, only the first B trial can be compared with previous studies. However, as pointed out by Butterworth et al. (1982) etc. this is the most important trial for analysis, being the most sensitive to the effect of the change of location.

Tests of Performance

The analyses below were used to answer two important questions. A first test of accuracy measured performance on the B trial relative to chance. If infant search was random then half the infants would search at A and half at B after the change in the location of the object. The binomial test was used to check this possibility. For $N>24$, the z test was used. This provides a good approximation to the binomial test (Siegal 1956) if a correction for continuity is made in the calculation.

A second type of analysis was carried out to compare Direct and Indirect conditions and age groups. This was done using the χ^2 test. The comparison between conditions enables the effect of blocking the direct path to the object to be assessed. The age comparison enables search errors to be charted developmentally.

TABLE 3.5 Experiment 1 (Summary Table)

Perseverative Errors by Infants on the First B Trial

Subjects	Indirect Condition (I)	Direct Condition (D)
(48)	13 (z = -3.03 p<.001)	5 (z = -5.34 p<.001)

Order of Conditions

	I 1st.	I 2nd	D 1st	D 2nd
	*	*	***	***
(24)	6	7	4	1

Age Groups

	Young	Old	Young	Old
	***		***	***
(24)	2	11	3	2

Age within Group

	8m	9m	10m	16m	17m	18m	8m	9m	10m	16m	17m	18m
	*	**	*	*	°			*	**	**		**
(8)	1	0	1	1	7	3	2	1	0	0	2	0

Sex of Infant

	Male	Female	Male	Female
	*	*	***	***
(24)	7	6	3	2

Side of Starting

	Left	Right	Left	Right
	*	*	***	***
(24)	6	7	3	2

* Statistically correct search at p<.05 binomial test.

** Statistically correct search at p<.01 binomial test.

*** Statistically correct search at p<.001 binomial test.

° Statistically incorrect search at p<.05 binomial test.

Accuracy on the first B trial relative to chance.

All infants reached repeatedly to the A location on A trials in both Direct and Indirect conditions. On the first B trial Table 3.5 shows that for the Direct condition infant's searched on the correct side of the screen for the object. Two sub-groups which did not reach statistical significance were the 8 month and 17 month old infants. In both case performance was correct for 6/8 infants and within the larger group search was statistically correct. There were no significant carry-over order effects.

For the Indirect condition, although search was statistically accurate overall (13/48 errors), the old group showed a divided pattern of search (11/24 errors). In contrast, the younger group who would be expected to still be in Piaget'sStage IV, were consistent in searching on the correct side of the apparatus. As pointed out above, these infants had not successfully retrieved the object on A trials (although they had reached directly to the object on the correct side of the apparatus). Within the old group, the 17 month sub-group showed significantly incorrect search contrary to expectations. This is difficult to explain when these infants would be expected to be in Stage V or Stage VI of object permanence.

One possible explanation concerns the nature of the perseverative detour path. It was observed that several infants were able to modify a reach through the incorrect hole in the apparatus to a successful reach. This was achieved by reaching through the incorrect hole and then right round the back of the apparatus retrieving the object at B. This involved considerable effort on the part of the infant. The discovery of a potential detour path from the incorrect side may or may not constitute a genuine error. It does logically offer a potential solution if not the ideal one. Hence these results must be viewed with some circumspection.

Comparison of Direct and Indirect conditions.

From Table 3.5 it can be seen that there were more errors on I than D trials. The McNemar χ^2 test for the significance of changes was used to compare change between I and D conditions where:

a = no. of infants searching correctly on the D condition but making an error on I condition.

d = no. of infants searching correctly on I condition but making an error on D condition.

There was no overall significant change in errors between D and I trials (a=11, d=4, χ^2=2.4, 1df n.s.). Tests of change (using the binomial test because of small expected frequencies) in age groups showed a significant change in the old group (a=9, d=0, p=.002) but not in the young group (a=2, d=3, p=.5). This confirms the finding that search errors were generated by the change from the Direct to the Indirect condition in the old group but not in the young group.

3.4. Discussion

The results of this experiment demonstrate that 8-10 month old infants are unable to solve a simple detour problem in manual space. However all the infants were able to remove a cover from a hidden object indicating transition to Piaget's Stage IV. This indicates that the ability to remove a cover does not imply an understanding of behind in a detour space. Developmentally it is clear that removing a cover from a hidden object precedes detour knowledge by at least 3 months in this sample.

All subjects were able to reach directly for an uncovered object placed immediately behind the hole in the detour screen. But by contrast the majority of 16-18 month old show a high degree of skill at the detour task from their very first attempt.

At the cognitive level, the failure of the 8-10 month old infants may be accounted for by the absence of an associativity rule specifying a route from subject (S) to object (O) may be accomplished via the edge of the screen (E). In terms of the logic of groups of displacements SE + EO = SO. However, both Lockman (1984) and Bruner (1970) report at least some success in this age group. This reported success in previous studies may be accounted for in several ways.

The use of screens with their edge at the infant's midline may encourage both accidental and leaning solutions resulting in success. In such cases the associativity rule would be unnecessary. Leaning around the screen would be available to the infant in Stage IV as it is a reversible action. By accomplishing the displacement SE by leaning around the screen, only the direct displacement EO remains (see Figure 2.1. chapter 2).

Accidental (or trial and error) reaching may lead the infant to complete the displacement SE. The remaining displacement EO may also be accomplished by accident where the object is close to the edge of the screen. Alternatively the remaining displacement SE may be made intentionally by visually guiding the hand in. In this experiment neither of these solutions was readily available owing to the design of the apparatus.

The predominant immediate response in the 8-10 month old infants was a direct reach to the screen at the location of the object. 88% of young infants and 46% of 16-18 month old infants came within this category. This reflected Bruner's finding. Also noted subsequently were banging, stroking and pulling the screen. It was difficult to interpret such activity but in some cases this appeared to be directed at removing the screen. If such an interpretation is correct, this would be similar to the Stage IV behaviour of removing a barrier to the object, a reversible action demonstrated by all infants in the pre-test. These results may reflect the takeover of reaching by cortical mechanisms enabling voluntary, instrumental control of distal movements by 16-18 months. The results for the 8-10 month old infants showed a remarkable similarity to those of Moll and Kuypers' rhesus monkeys with ablations of the pre-motor cortex (Moll and Kuypers 1977) in a similar problem. The evidence for a failure of inhibition of direct reaching in younger subjects is equivocal. Although subjects failed, they did shift to other actions directed away from the object. However these were either directed at removing the barrier or they were exploratory and not necessarily goal directed at all.

The discovery of perseverative errors in the Indirect condition for 16-18 month old infants was contrary to the hypothesis that errors would be found in stage Iv infants only. As explained the procedure permitted corrections within the trial and hence the results cannot be compared directly with experiments involving a non-correction procedure. The failure to discover errors in the 8-10 month old group on the B trial may be because the object was not recovered on the A trial. A replication with a no corrections procedure on A and B trials would be necessary to further evaluate these findings.

As reported in the results section, some infants were able to reach through the hole contralateral to the object and reach right around the back of the screen. These infants were using a detour route which although inefficient was at least potentially successful. Whether these are genuine errors comparable with those in other studies is open to question. Other studies of locomotor detour and maze learning have found that perseverative errors only occur before 14 months (McKenzie and Bigelow 1986) and around 14 months (Heth and Cornell 1980).

Two possible explanations for the results are suggested. If the infant locates the object at A then the new schema at A will require updating when the object is moved to B. The failure to update that schema on the B trial may reflect a lack of available information processing capacity. McKenzie and Bigelow (1986) suggest this may be responsible for the generation of errors in a locomotor detour problem. The new detour response may be using up all the infant's available attention.

Alternatively this may be a further example of Bower's observations of repetitive processes in development (Bower 1974b). Such responses may reflect the need to co-ordinate the allocentric and egocentric codes (Butterworth 1977) hypothesised here in Stage IV. At this later and more advanced stage the detour space may still be represented by a limited egocentric code but the lateral (left or right) location of the object by a separate allocentric code. If this were the case then a failure to co-ordinate the two codes would result in equiprobable search at A and B. McKenzie and Bigelow (1986) suggest similar failures to update location codes may explain their results with infants up to 14months of age. These accounts are speculative though and further experimentation is required to evaluate the phenomenon.

3.5. Summary

1. In Experiment 1 infants were tested on a manual detour task in which they were required to retrieve an object from behind a transparent screen. Infants were also tested on a direct reaching task using the same apparatus. In addition all the infants were able to retrieve an object from under an opaque cover.

2. Within the study infants were tested for spatial perseverative errors in both detour and direct reaching conditions.

3. 8-10 month old infants failed at the detour task but succeeded on the direct reaching task. These young infants showed a charateristic ineffective direct reach to the visible locus of the object when it was behind the transparent screen. In contrast the majority of 16-18 month old infants were able to retrieve the object from behind the screen using a detour reach. Many of the older group still began their attempt at the problem with a direct reach. These results suggested that any transition in the ability to solve the detour problem occured between 11 and 16 months of age.

4. These results are consistent with Piaget's theory and the development of associative groups of displacements in stage V for visible detour problems. At the neuro-psychological level they may refect the takeover of reaching by cortical control allowing voluntary reaching based on a representation of perceived space.

5. The presence of perseverative search errors in the detour task by the 16-18 month group was noted. These errors were not found in the 8-10 month group nor in the direct reaching task for either age group. This result may reflect the lack of successful detour reaching in the younger group. Further investigation of the nature of these errors is required.

6. The usual non-correction procedure was not adopted and reaching through the incorrect hole allowed a potential detour path around the back of the apparatus. This was exploited by some infants. The nature of these errors suggested two further possible explanations. Errors in the older group may reflect a lack of available information processing capacity. Alternatively the infants may fail to update a code relating the new detour schema to a lateral spatial code for the object.

CHAPTER FOUR

EXPERIMENT 2: DETOUR REACHING IN 12-14 MONTH INFANTS

4.1. Introduction

In this chapter an experiment is described which replicates that in chapter three for 12,13 and 14 month old infants. In the previous study it was discovered that in the detour task used, infants 10 months old and younger totally failed to retrieve an object placed behind a transparent screen. However success was forthcoming from infants aged 16, 17 and 18 months. It was expected that a transition in performance would be found in the age groups between 10 and 16 months. In order to investigate this phenomenon further, infants intermediate between these age groups were tested. It was hypothesised that infants within this age group would show a growing ability to inhibit direct reaching and perform manual detours. This ability may reflect underlying neural maturation (Moll and Kuypers 1977) and the cortical control of sub-cortical processes.

At the cognitive level the transition to Piaget's sensorimotor stage V occurs at around 12 months. It is in this period of development that the schemas exhibiting associative group properties such as detours develop (Piaget 1954). This is restricted to visible detour problems, for example with a transparent screen. As discussed in chapter 1, detours involving opaque screens are not solved until stage VI as these require mental representation of occluded space. Only transparent detours are dealt with here but others have suggested that for opaque detours Piaget's prediction was incorrect (Bruner 1970: Lockman 1984).

It was therefore hypothesised that genuine associative groups would be apparent in this age group. The ability to perform manual detours reflects this underlying growth in spatial understanding. As noted in experiment 1, the failure of stage IV infants performing detours in visible space are unequivocal when the displacement of self action is not available. Detours are on this view a stage V acquisition for visible displacements.

4.2. Method

Subjects

24 infants served as subjects. These were divided equally by sex and into 12, 13 and 14 month old sub-groups.

12 months: 8 infants, (4 female, 4 male), mean age = 1 year 13.6 days, S.D. = 9.4 days, (age range 1 year 2 days-1 year 29 days).

13 months: 8 infants, (4 female, 4 male), mean age = 1 year 46.0 days, S.D. = 11.8 days, (age range 1 year 32 days-1 year 61 days).

14 months: 8 infants, (4 female, 4 male), mean age = 1 year 76.1 days, S.D. = 11.4 days, (age range 1 year 64 days-1 year 90 days).

Three infants aged 1 year 20 days, 1 year 37 days and 1 year 41 days were excluded from the sample because they fussed and failed to complete the experiment.

Apparatus, Design and Procedure.

These were identical to those described in experiment 1. The block of 24 infants was subjected to the same counter-balanced design as each of the two blocks of infants in experiment 1.

Scoring

This was done in an identical fashion as experiment 1.

Inter-observer reliability

A second independent scorer viewed the video-films of at least 10% (3) of subjects. For the categories of Success or Failure agreement was reached on 34/36 trials (94%). For all the other measures agreement was in excess of 91%.

4.3. Results

Examples of Infant Performance

Described here are two typical responses made by infants in this experiment. On the Indirect task, there was a transition from virtually no success at 12 months to a high level of succcess at 13 and 14 months. The two subjects illustrate failed and successful patterns of response.

Subject 1

This was a 12 month old male infant who received his Indirect trials first with the object on his left on the first trial. He fixates the object and reaches along the line of sight with his ipsilateral (left) hand, first grasping and then pointing at the object. He withdraws this hand and reaches up grasping and pulling the barrier with his left hand. He now repeats his line of sight reach.

On his second trial, the object is placed on his right. He immediately reaches out along the line of sight with with his ipsilateral (right) hand and points. He withdraws this hand and pushes with both his palms against the screen. His response to Indirect trials continues in this manner.

On his first Direct trial, he initially continues his pushing activity on the barrier. Very quickly though he re-fixates the object and reaches out with his contralateral (left) hand and retrieves the object. He succeeds on all subsequent Indirect trials.

Subject 24

A 14 month female infant performs effortlessly on her Direct reaching trials. On her first Indirect trial, the object is placed on her left. She reaches out along the line of sight with her ipsilateral (left) hand and points at the object. She withdraws this hand and reaches through the left hole in the barrier and in to recover the object.

On the next trial, with the object on her right, she reaches out with her contralateral (left) hand along the line of sight. She shifts to an indirect stategy and both left and right hands reach through the respective holes in the barrier with the ipsilateral hand retrieving the object. She succeeds on all subsequent trials but shows some evidence of perseverating to the inappropriate hole.

Success then is often preceded by reaching along the line of sight.

Pre-test

All the infants were able to remove the cover and retrieve the hidden object on the pre-test.

First Response

The infant's first responses in the Indirect condition were divided into 3 categories (as in Experiment 2). These were Indirect (detour) reach (IR), Direct reach to the object (DR) and banging stroking or pulling the Barrier (B). These results are shown in Table 4.1 and may be compared with those in Table 3.1. The graph in Figure 4.1 shows the comparison with the 8-10 and 16-18 month age groups.

Table 4.1 Experiment 2

First Response of Infants in the Indirect Condition

Response	IR	DR	B	Total
12-14 m	2*	16	6	24
	(8%)	(67%)	(25%)	

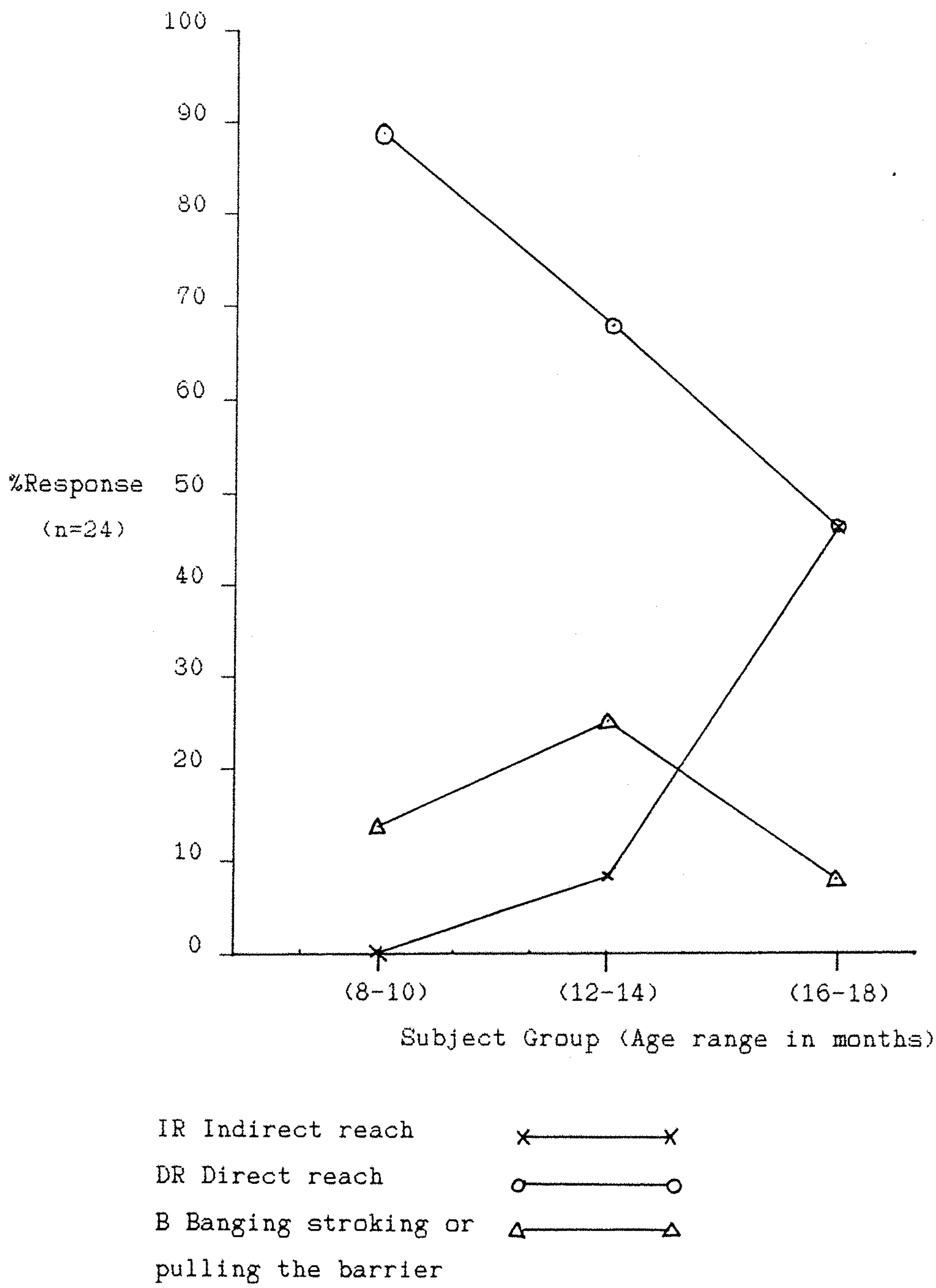
* There was 1 infant in this group who performed an unsuccessful detour reach.

This distribution of responses was significantly unequal (χ^2=14.5, 2df p<.001). Further pairwise analyses showed that the Direct Reach was more frequent than either the Indirect Reach (χ^2=10.89, 1df p<.001) or the banging pulling or stroking the Barrier responses (χ^2=4.55, 1df p<.05). Thus the characteristic initial response in this age group was a direct reach to the barrier.
A

Figure 4.1. Experiments 1 and 2

Graph Showing Infant's First Response on

Their First Indirect Trial



Successful Responses in the First Direct and Indirect Trial.

The same analyses were carried out in experiment 2 as on experiment 1. Success on Direct trials was at ceiling level. Table 4.2 indicates that only 2 infants failed to retrieve the object on their first Direct trial. There were thus no effects of order (using tables of critical values in the Fisher test (Siegal 1956)) (C=10 critical value=8, n.s.), sex (C=11 critical value=6, n.s.) or side , left or right (C=11 critical value=6, n.s.). This result was similar to those of other age groups in experiment 1.

Comparison of performance on the Direct and Indirect conditions were made using the McNemar χ^2 test. Overall, change in performance compared:

a) The number who were successful on the Direct but failed the Indirect task, with

d) the number who were successful on the Indirect but failed the Direct task.

Overall Indirect tasks were more difficult than Direct conditions (a=14, d=0, χ^2=12.07 1df p<.001). Comparisons between I and D conditions within this age group showed that 12 month infants found D easier than I (a=7, d=0, p=.008 (binomial test used because of small expected frequencies). The 13 and 14 month groups were combined for this test, again because of small frequecies of change. This showed again that D trials were easier than I trials ((a=7, d=0, p=.008 (binomial test).

For the Indirect trials, Table 4.2 shows that overall 8/24 infants succeeded on their first trial. χ^2tests showed no significant differences in performance between sexes (χ^2=1.69, 1df n.s.), side of object (left or right) (χ^2=0.75, 1df n.s.) or order of trials (χ^2=1.69, 1df n.s.). Comparison of results between age levels in this group was made using the Fisher test as expected frequencies were too low to use the χ^2 test. Pairwise χ^2 tests showed differential performance between 12 and 14 month infants (C=4 critical value=5, p<.05). There were no significant differences between 12 and 13 month subjects (C=5 critical value=4, n.s.)n.s.) nor between 13 and 14 months subjects (C=3 critical value=0, n.s.). This result indicates a transition in performance on the first Indirect trial between the ages of 12 months and 14 months. Next this finding will be compared with results over the complete 6 trials.

TABLE 4.2 Experiment 2

Number of Infants Successful on their First Trial

	Conditions			
Subjects (n)	Indirect Condition (I)		Direct Condition (D)	
(24)	8 (33%)		22 (92%)	
Order of Conditions				
	I 1st.	I 2nd	D 1st	D 2nd
(12)	2	6	12	10

Age within Group						
	12m	13m	14m	12m	13m	14m
(8)	0	3	5	7	7	8

Sex of Infant				
	Male	Female	Male	Female
(12)	6	2	11	11
Side of Object				
	Left	Right	Left	Right
(12)	3	5	11	11

Performance over the Six Direct and Indirect Trials

To assess overall performance a score out of 6 successful reaches for the Direct and Indirect conditions was computed. These results are shown in Table 4.3. A paired Student's 't' test showed a significantly better performance on Direct than Indirect trials; $t = 6.05$, 23df, $p<.001$.

An Analysis of Variance was computed with age and order of trials as independent variables. The other counterbalanced variables (a) side of starting and (b) sex of infant were excluded from the analysis. Neither of these variables contributed significantly to success: (a) left mean = 2.42; right mean = 2.58, $t=0.35$, 22df, n.s.; (b) male mean = 2.67; female mean = 2.33, $t=0.30$, 22df, n.s.

The dependent measure, success out of 6 Indirect trials was transformed $x'=(x+0.5)^{1/2}$ to render the bi-modal (Poisson) distribution of the data more suitable for the analysis.

The results of this analysis are shown in Table 4.4. The main effect of age was the only significant result ($F=8.06$, df 2,23, $p<.01$). Inspection of Table 4.2 shows the mean scores were: 12 months = 0.13, 13 months = 2.88 and 14 months = 4.50. Comparisons were made between pairs of age groups using Scheffe's procedure, testing F ratios against $F' = 2F$ (Kirk 1968). The comparison between 12 and 14 month infants was significant ($F=15.76$, df 1,18, $p<.05$). Other pairwise comparisons were not significant; 12 and 13 months ($F=6.31$, df 1,18 , n.s.) and 13 and 14 months ($F=2.13$, df 1,18, n.s.). Thus there was a significant transition in performance between the ages of 12 months and 14 months. This reflects the similar finding noted above for the first trial out of the 6 Indirect trials.

As there was no significant effect of order of trials (Direct or Indirect first), it could not be concluded that practice on the Direct task assisted performance on the Indirect task.

TABLE 4.3. Experiment 2

Mean Score of Successful Retrieval of Object Out of 6 Trials

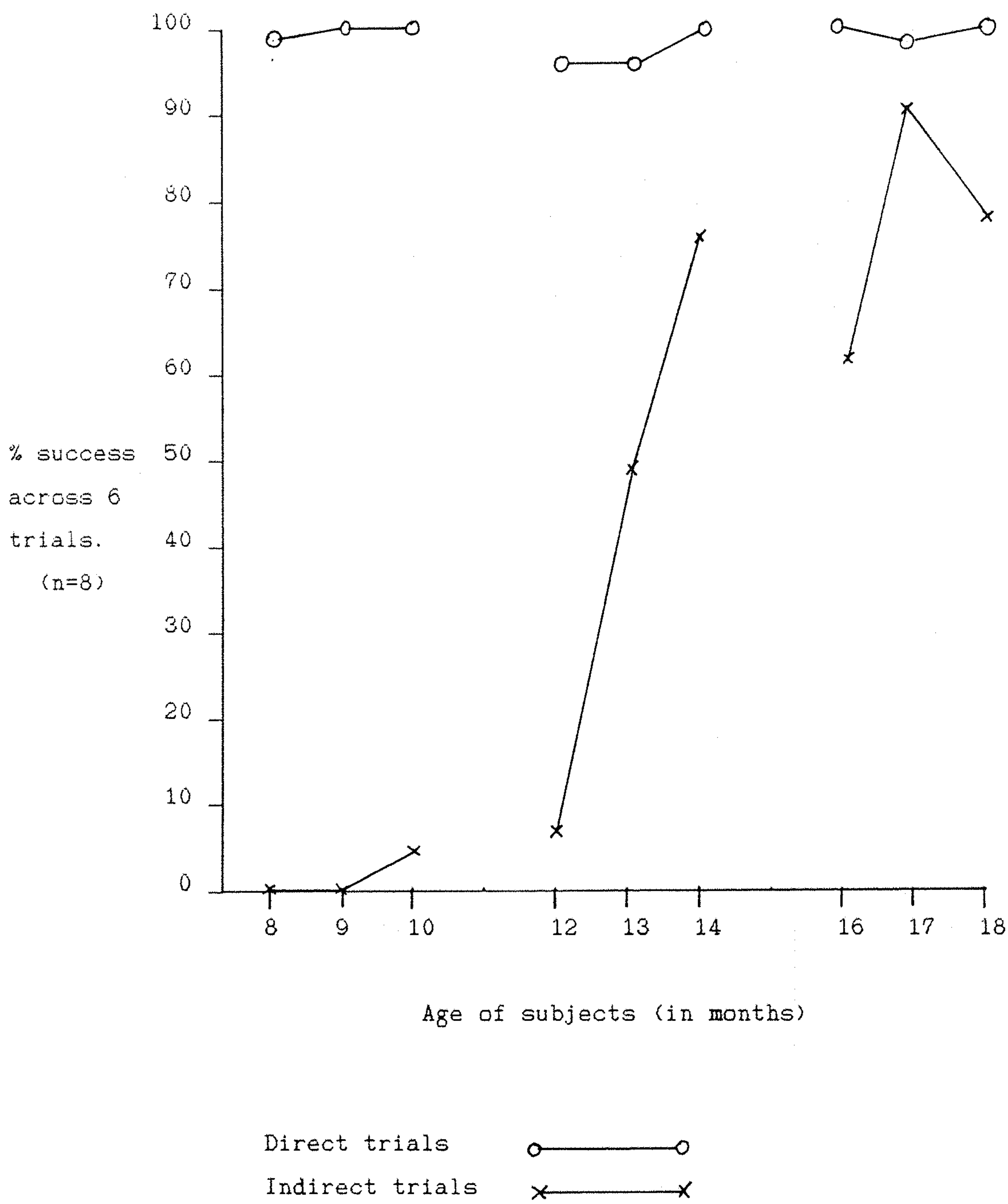
Subjects (n)	Indirect Condition (I)			Direct Condition (D)		
(24)	2.50			5.83		
Order of Conditions						
	I 1st.		I 2nd	D 1st		D 2nd
(12)	2.25		2.75	6.00		5.67
Age within Group						
	12m	13m	14m	12m	13m	14m
(8)	0.13	2.88	4.50	5.75	5.75	6.00
(%)	(6)	(48)	(75)	(96)	(96)	(100)
Sex of Infant						
	Male		Female	Male		Female
(12)	2.67		2.33	5.75		5.92
Side of Starting						
	Left		Right	Left		Right
(12)	2.42		2.58	5.75		5.92

TABLE 4.4 Summary of Analysis of Variance Experiment 2

Source of Variance	Sum of Squares	d.f.	Mean Square	F Ratio	p
Order	0.22	1	0.22	0.46	n.s.
Age	7.74	2	3.87	8.06	$p<.01$
Order×Age	.012	2	.006	0.13	n.s
Residual	8.56	18	0.48	0.48	–
Total	16.53	23	–	–	–

Figure 4.2 Experiment 1 and 2

Graph Showing % Success in Indirect and Direct Conditions



Perseveration

The tendency for 16-18 month infants to perseverate when reaching for the object in the Indirect condition was not apparent in the 12-14 month infants. As in experiment 1 an error was defined as search on the wrong side (left or right) of the screen. This does not imply that the infant successfully retrieved the object from behind the screen. All the infants reached to the A location during A trials. The data are for the first B trial.

Accuracy on the first B trial relative to chance.

Inspection of Table 4.5. shows that infants searched on the correct side (left or Right) of the screen for the object in the Direct condition (3/24 errors). The binomial test showed this to be highly significant ($p<.001$). All sub-groups searched correctly except the 13 month sub-group (2/8 errors). Infants searched on the correct side whether they had received Indirect trials first or not.

For the Indirect condition search was correct (3/24 errors). The binomial test showed this to be highly significant ($p<.001$). All age sub-groups searched significantly correctly except the 13 month sub-group (2/8 errors). Infants who received Direct trials first showed the divided pattern of search (3/12 errors, n.s.).

Comparison of Direct and Indirect conditions.

From Table 4.5. it can be seen that there were an identical number of search errors in Direct and Indirect conditions. The McNemar test was used to compare performance between D and I conditions where:

a = no. of infants searching correctly on the D condition but making an error on the I condition.

b = no. of infants searching correctly on I condition but making an error on the D condition.

There was no overall significant change in errors between D and I trials (a=3, d=3, p=.656 (binomial test used because of small expected frequencies)). Further analysis within age sub-groups was impossible because a and d were too small.

TABLE 4.5 Experiment 2 (Summary Table)

Perseverative Errors by Infants on Their First B Trial

Subjects (n)	Indirect Condition (I)			Direct Condition (D)		
(24)		*** 3			*** 3	
Order of Conditions						
	I 1st.		I 2nd	D 1st		D 2nd
(12)	*** 0		3	** 1		* 2
Age within Group						
	12m	13m	14m	12m	13m	14m
(8)	** 0	2	* 1	* 1	2	** 0
Sex of Infant						
	Male		Female	Male		Female
(12)	* 2		** 1	* 2		** 1
Side of Starting						
	Left		Right	Left		Right
12	* 2		** 1	* 2		** 1

* Statistically correct search at p<.05 binomial test.

** Statistically correct search at p<.01 binomial test.

*** Statistically correct search at p<.001 binomial test

4.4. Discussion

The results of this experiment show a transition in performance between 12 and 14 months of age. This was demonstrated from the first Indirect trial as well as across the 6 Indirect trials. However the first response to the Indirect condition was usually a direct reach to the object at the barrier for most infants. The inhibition mechanism postulated by Moll and Kuypers (1977) to explain the failure of their rhesus monkeys may be relevant here. They pointed out that in order to solve a transparent detour problem it is necessary to inhibit direct reaching. The results of their ablations of the monkeys pre-motor cortex may have been to disinhibit the sub-cortical direct reaching. On this theory, the experimental monkey and by analogy the infant are unable to voluntarily control their reaching. During the postulated growth of the pyramidal neural pathways there may initially be a period of intermediate performance. Some of the 16-18 month old infants showed this trend as well. The initial direct reaching gives way to indirect reaching and as Bruner (1970) mentions performance may initially be poorly orchestrated.

At the cognitive level these results show a transition to de-centred manual skill demonstrating associative group properties. This occurs between 12 and 14 months indicating that it is a stage V achievement. As this result was found on both the first Indirect trial and over 6 trials it appears to be an all or nothing acquisition. Other researchers have reported a similar disconinuity in cross-sectional (Bruner 1970) and longitudinal (Lockman 1984) studies of detours. With the elimination of the possible displacement of self action these results are more conservative than either Bruner's or Lockman's.

Bruner quotes a 30% success rate for his 6-9 month group and Lockman found success at a mean age of 10.7 months. In this study the success rate was 6% at 12 months, 48% at 13 months and 75% at 14 months. This difference might be accounted for by virtue of Lockman's study being longitudinal. Infants may have acquired detour knowledge through enriched experience at the task. This would not seem to be the case as Bruner's study was cross-sectional. Bruner specifically states that learning did not occur across trials in his study.

In describing such forms of problem solving which are sudden and do not arise from trial and error we are justified in using the term insightful in a descriptive sense. These results fit Kohler's descriptive use of the term precisely. However this experiment and experiment 1 did not encourage the infant to explore the apparatus. Neither can the infants' developmental histories with regard to experience of transparent materials be described. Hence chronological age is the principal independent variable. With more experience or training at the task it is entirely possible that younger infants may be able to perform manual detours. The support given for Piaget's theory is unequivocal though. Any ability that infants 1 year or younger may have did not generalise to this version of the task. It follows that development of associativity in perceived space is incomplete prior to 13 months at the earliest.

There are though possible reasons why this study was conservative in its conclusions. This concerns the design of the experiment reported here. In this study the effects of spatial changes were used to investigate search errors. Whilst these were rare in this age group, the changes made may have affected detour performance adversely. In addition the 15 second trial period may not have been sufficient for younger infants to organise a detour response. Both Lockman and Bruner gave their subjects considerably longer on each trial. Lockman gave aproximately 1 minute and Bruner up to a point of failure of at least 30 seconds without any progress. The possibility of trial and error or fortuitous success would be increased with a longer trial time. In such instances the characterisation of perform as showing insight might be inappropriate. In the next experiment these possibilities will be examined.

The results for search errors show overall correct search for both Direct and Indirect conditions. Only the 13 month group failed to show statistically correct search (2/8 errors for both I and D conditions). Thus overall the infants in the stage V age group were able to search correctly and this would accord with predictions from Piaget's theory and Butterworth's (1977) theory.

In the context of errors found in experiment 1 amongst 16-18 month old infants, this may give support for the idea of repetition in development (Bower 1974b). The apparent gap in errors up to 16 months might generate such a hypothesis. Bower noticed such gaps in performance on search tasks testing the development of understanding the 'behind' relationship earlier in the first year.

4.5. Summary

1. In Experiment 2 infants were tested using the same apparatus and prodedures as Experiment 2. Infants were tested on a Direct and an Indirect reaching task. Perseverative errors were also tested for in the Direct and Indirect tasks.

2. All the infants were able to retrieve an object from under a cover indicating at least a stage IV level of object permanence. Infants in this age have usually progressed to sensorimotor stage V.

3. The results showed a ceiling effect for the Direct task and a transition between 12 and 14 months from failure to success on the Indirect task.

4. It was proposed that this might reflect both a growth of cortical control over distal components of reaching at the neural level and the development of associative groups of displacements at the cognitive level.

5. The conservative nature of these results in comparison with previous studies was discussed. It was suggested that infants in other studies may have leaned around the barrier, this displacement reducing the obstruction of the barrier. This might be possible during stage IV in Piaget's theory explaining the discrepancy between these and other findings. Further experiments will test this and other hypotheses suggested.

CHAPTER FIVE

EXPERIMENT 3: TRAINING STUDY ON MANUAL DETOUR REACHING 8 and 10 MONTH GROUPS.

5.1. Introduction

Experiment one showed that infants of 8-10 months of age totally failed to perform a simple manual detour to retrieve an object placed behind a transparent screen. It was suggested that this may reflect a neuro-psychological immaturity and restricted cognitive inability in infants one year old and younger. These may be translated into the ability to inhibit direct reaching and make visually guided distal movements under instrumental cortical control. At the related cognitive level the results reflect the inability to perform actions characteristic of associative groups of displacements which do not appear until stage V (roughly 12-18 months) for visible detours (Piaget 1954). Experiment two showed this ability developed between 12 and 14 months. However other researchers have found some success on similar tasks at an earlier age. Bruner (1970) showed that in similar spatial conditions for 6-9 month infants 30% of trials ended in success. In a longitudinal study (Lockman 1984), the mean age of success with a criteria of 2 out of 3 trials was 10.7 months. The results of these studies are inconsistent with the findings of experiments one and two.

The design of the apparatus used by Bruner and Lockman may have permitted a displacement of self (or leaning) solution as illustrated in Figure 2.1. However there are other possible reasons for the conflicting results. First previous studies have given infants a longer trial time. The 15 second trial time in experiments 1 and 2 may not have been enough time for infants to organise a successful response. Second the spatial changes in experiments 1 and 2 were designed to investigate perseveration as well as detour problem solving. These spatial changes from left to right (or vice-versa) may have had an adverse effect on infant performance, even though perseverative responses were uncommon in young infants. Also the 3 second delay interposed before infants were allowed to search might have affected attention in such a way as to make the detour response unavailable.

To check these possibilities, infants aged 8 and 10 months old were retested with a trial time identical to that used by Bruner (1970). Each trial was terminated after successful reaching or after 30 seconds with no advance. Lockman (1984) gave his infants up to approximately 1 minute on each trial but Bruner's subjects had a higher success rate so his procedure was adopted.

In order to rule out the second possible explanation the new sample was tested without a 3 second delay and with trials on same side of the apparatus for the Test and ReTest conditions. This ruled out the possibility that attentional or spatial changes may have accounted for the poor performance of 8-10 month old infants. Lockman (1984) did not make any spatial changes within blocks of trials for transparent detour problems. Bruner did however, and he reports some disruption of performance due to perseveration (Bruner 1968). Hence to optimise performance, trials may need to be given without any changes in the spatial conditions across trials.

In a training study designed to investigate the nature of instruction and reciprocity in mother-infant diads, Kaye (1970) noted that 6 month old infants showed some success on a detour test. This study, (reviewed in chapter 1) had 3 levels of test. The infants received a detour Test prior to training by their mother. They then received a Re-test after training and finally a Transfer test. In the Transfer test the infant was tested with the screen and object on the opposite side (left or right) of the apparatus.

In the Kaye training study the screen was always at the infant's midline and the object placed just inside the edge of the screen. This spatial arrangement was found to be the easiest using identical apparatus (Bruner 1970). The results of the study are complex but success rates (criterion at least one successful retrieval) were: Test 19%, Re-test 34%, Transfer 21%. Although these percentage figures indicate some effects of learning, the only significant efects reported by Kaye were those relating to measures used in analysing the training period and not test peformance. The only predictor of success on the Re-test was success on the Test.

No training studies have to date been reported with older infants on the detour task. In this experiment groups of 8 and 10 month old infants were tested. These ages were chosen as they showed no success in experiment 1 and 2 but some success in other studies reviewed here. To maximise the possibility of success and produce a more relaxed and natural situation for the infant a training element was incorporated into this study. In a similar design to Kaye's, the infants in this study were given training session following their Test. They were then subsequently Re-tested and given a Transfer test. This design enabled each infant to be her own control, comparing performance before and after training.

Thus an additional aim of the study was to establish whether infants could be taught to solve a detour problem independently by their mothers. This was in addition to the main aim of establishing the reasons for the failure of young infants in experiments 1 and 2. If the children performed better given a longer period on each trial, this would be apparent if success occurred after 15 seconds. If the spatial change from left to right (or vice-versa) was responsible for the lack of success in experiments 1 and 2 then performance on the Transfer test would be affected.

5.2. Method

Subjects

Subjects were 24 infants, with equal numbers of each sex, divided into two age groups: 8 months and 10 months.

Group 1: 12 infants, (6 female, 6 male), mean age 251.7 days, S.D. 6.6 days (age range 248 days-269 days).

Group 2: 12 infants, (6 female, 6 male), mean age 322.3 days, S.D. 4.6 days (age range 316 days-330 days).

Five infants aged 249 days, 265 days, 321 days, 327 days and 327 days were excluded from the samlple because they fussed and failed to complete the experiment

Apparatus

This was identical to the detour apparatus used in experiments 1 and 2.

Design and Procedure

Each mother and infant was seen in their own home. The experimenter set up the apparatus and the video-camera. During and following this, for a period of 10 minutes, the infant became familiar with the experimenter and the mother was informed of her part in the experiment.

The infant was then sat in the low chair and strapped in for safety. The experimenter then placed the object in the open space behind the hole in the apparatus (Direct trial) and the infant recovered it. No delay was imposed before the infant was allowed to search. Next the infant received 5 trials with the object behind the screen on the same side (left or right). The object was passed over the top of the apparatus to prevent her simply following the trajectory of the object. Each trial was terminated after successful reaching or after 30 seconds with no advance (identical to Bruner's procedure (Bruner 1970)). After each trial the toy was recovered from the infant. If she was unsuccessful she was shown the toy. The toy was then replaced behind the screen for the next trial.

Following 5 trials (Test), the mother was allowed to assist the infant for a period of 5 minutes. During this period the only limitations on activity of the mother or infant was that the infant remained in the chair and the video-camera should not be obstructed. She was told *'Well (baby) might be able to do better in this game if you helped her. See if you can teach her how to solve the detour problem. Do anything you think might help her but please leave (baby) in the chair and make sure the camera can see her.'*

After the training period, the infant was re-tested on the detour test 5 times (Re-test). This re-test was on the same side (left or right) as the original test. Finally, the infant was tested on a Direct test once on the opposite side (left or right) of the apparatus and then 5 times (Transfer test) for the Indirect test. The aim of this was to see whether any learning that took place transferred to the opposite location (This was similar to the procedure used by Kaye 1970) . The Direct trial before the Transfer test was given to eliminate any perseverative effects to the Test side of the apparatus and to provide a further baseline with which to compare Indirect performance.

Scoring

The video-film of each infant's Test, Re-test and Transfer test was carefully examined and scored for Success and Failure on each trial of the Test, Re-test and Transfer test.

Inter-observer reliability

The video-films of 10% (3) of infants were examined by an independent judge and scored for Success or Failure as above. Agreement was reached on 49/51 trials (96%).

5.3. Results

Successful Reponses in the First Direct and Indirect Trial on Test, Retest and Transfer.

The number of infants giving a successful response on their first trial is shown in Table 5.1. All the infants succeeded at the Direct test both before the Test and Transfer. This was not surprising as infants were given a period of up to 30 seconds without further advance. There were thus no statistical differences between age, sex or side (left or right) (χ^2=0, 1df, n.s. in each case).

Performance on the Indirect condition was very low with only 3/12 of the 10 month old infants showing any success at all and none of the 8 month infants. The Test and ReTest Indirect conditions were each compared with the Direct condition trial preceding the Test. The Transfer Indirect test was compared with the Direct condition immediately preceding that condition. Analysis of change between these conditions was made using the McNemar χ^2 test which compared:

a) The number of infants who were successful on the Direct but failed the Indirect task. with

d) the number who were successful on the Indirect but failed the Direct task.

One tailed tests were used because I conditions were expected to be more difficult than D conditions. Overall there was significant change in performance between Direct and Indirect conditions on the Test, ReTest and Transfer. In each case respectively I conditions were significantly more difficult than D conditions, (a=23, d=0, χ^2=21.04, 1df p<.001) (a=23, d=0, χ^2=21.04, 1df p<.001) (a=21, d=0, χ^2=19.05, 1df p<.001)

TABLE 5.1. Experiment 3 (Summary Table)

Number of Infants Successfully Retrieving the Object

on the First Trial in Each Block.

Subjects (n)	Indirect Test		Indirect ReTest		Indirect Transfer		Direct PreTest		Direct PreTransfer	
Total (24)	1		1		3		24		24	
Age	8m	10m	8m	10m	8m	10m	8m	10m	8m	10m
(12)	0	1	0	1	0	3	12	12	12	12
Sex	M	F	M	F	M	F	M	F	M	F
(12)	1	0	1	0	2	1	12	12	12	12
Side	L	R	L	R	L	R	L	R	L	R
(12)	1	0	1	0	2	1	12	12	12	12

TABLE 5.2. Experiment 3 (Summary Table)

Mean Score of Successful Retrieval of Object Out of 5 Indirect Trials.

Subjects (n)	Test		ReTest		Transfer		Total (n=24)	
Total (24)	0.13	(3%)	0.50	(10%)	0.42	(8%)	0.35	(7%)
Age months	8m	10m	8m	10m	8m	10m	8m	10m
(12)	0.00	0.25	0.00	1.00	0.08	0.75	0.03	0.67
Sex	M	F	M	F	M	F	M	F
(12)	0.25	0.00	0.67	0.33	0.50	0.33	0.47	0.22
Side of start	L	R	L	R	L	R	L	R
(12)	0.25	0.00	0.67	0.33	0.67	0.17	0.53	0.17

For the both the 8 and 10 month old group the results confirmed that Direct trials were easier than Indirect trials. For the 8 month group, Test, Retest and Transfer showed the same significant result in each case, (a=12, d=0, χ^2=10.08, 1df p<.001). For the 10 month group, the Test(a=11, d=0, χ^2=9.09, 1df p<.001), ReTest ((a=11, d=0, χ^2=9.09, 1df p<.001 and Transfer (a=9, d=0, binomial p=.002 (binomial test used because of low expected frequencies) all showed a similar pattern.

For the Indirect conditions the frequency of correct responding was very low, similar to that of infants in experiment 1. A Cochran Q test (tested against 2 tailed χ^2 distribution) was performed to establish if there was any overall difference between Test, Re-test and Transfer conditions. There were no significant differences (Q=4.00, 2df, n.s.) and thus there was no overall effect of training or transfer.

Further statistical comparisons between groups were impossible because of the low frequencies of success.

Performance Over the Five Indirect Trials on Test, Re-test and Transfer.

The mean Indirect success scores (out of 5) are shown in Table 5.2. These showed a low level of responding similar to that in experiment 1 for similar age groups. Overall the high proportion of 0 scores made parametric tests inappropriate. The mode score in each condition was 0.

Mann Whitney U tests were performed between groups to establish that there was no effect of sex of infant or side of starting (left or right). Because of the high proportion of 0 scores the results were summed across Test, Re-test and Transfer for these analyses. The calculations showed that there were no such effects of sex or side; (U=56, 1df n.s.; U=66, 1df n.s. respectively). A similar analysis showed that there was no significant effect between 8 and 10 month infants, (U=53, 1df n.s.).

The question of whether there was an improvement in performance across conditions was tested using the Wilcoxon test. The high proportion of 0 scores made parametric tests inappropriate. All age, sex and side groups were shown above to have no overall effect. Thus the trend analysis was of the main effect only. The low frequency of success made this necessary and interactive affects were not analysed.

For this test the calculation compared:

N) The number of infants who showed change between conditions with

T) The Wilcoxon test statistic T.

Comparing a) Test and Retest, b) ReTest and c) Transfer and Test and Transfer there was no difference in performance (a. N=4, T=0, n.s.; b. N=6, T=3.5, n.s.; c. N=5, T=0, n.s.).

There were thus no learning effects shown across the experiment and it can be concluded that the training had no effect on performance. This does not preclude the possibility that other longer forms of training might have an effect. Starting from a very low level of performance it was not surprising that there were no effects of change when infants were tested on the Transfer test with the object on the opposite side (left or right) of the apparatus.

Time Taken to Solve the Detour Problem

The subjects' first successful responses were timed to establish whether infant performance was enhanced with a longer trial time. Subsequent successful Indirect reaches may have been faster and subject to practice effects. The mean time taken was 12.9 seconds (S.D.= 7.7 seconds, range 3.3 - 26.1 seconds). Only 1 subject exceeded the 15 second trial time of experiments 1 and 2. 5 subjects retrieved the object in less than 15 seconds. Comparing these using the binomial test showed no difference in the frequencies of infants taking more or less than 15 seconds (binomial p=.11, n.s.). However the large number of subjects who totally failed given a longer time period indicated that the longer trial period gave no significant advantage towards successful performance.

5:4 Discussion

The results of this study showed that 8 and 10 month old infants failed to solve a manual detour test under enhanced conditions. In comparison with similar age groups in experiment 1, the infants in experiment 3 received their Indirect trials under conditions which gave a longer trial time, no spatial changes after the first trial (from right to left or vice-versa) until the Transfer test and there was no 3 second delay before search.

Although it would be statistically unsound to compare the results between different experiments, the percentage success rates indicate a similar pattern of failure in both 8 and 10 month old groups. For 8 and 10 month groups respectively experiment 1 showed 0% and 4% success rates compared with 0% and 5% in experiment 2 Test condition. Analysis showed that after training Retest and Transfer conditions did not significantly improve on Test performance.

These results are a strong indication that the subjects in previous studies showing higher levels of success prior to one year of age were accessing different mechanisms in solving the task. The 6-9 month infants in Bruner's study succeeded on 30% of trials in conditions where the infant reached for an object placed just inside from the edge of the barrier. The apparatus he used though was significantly different from the apparatus used here. The apparatus used by Bruner and Kaye comprised a box at the front of which was fitted a transparent (or opaque) screen. The aperture through which the infant reached was 18 inches wide by 5½ inches high (4 inches narrower for midline conditions) or 46cms×14cms.

The apparatus used by Lockman (1984) was a simple upright screen 14cms. wide×30.5cms. high slotted into a table top. The goal object was placed centrally behind the screen. Thus the aperture extended from 7cms. either side of the infant indefinitely. In contrast the aperture used in this study was an arch shaped hole 10cms. wide×8.5cms. high. It was noted earlier that it was possible that the infant might succeed by accidental contact or by a leaning (displacement of self) action followed by a direct reach. Both possibilties are more probable with the larger aperture used by Bruner (and Kaye 1970) and Lockman.

There is an alternative explanation which is suggested by the theory of direct perception (Gibson 1966; 1979). In Gibson's analysis of perception what is seen is intimately connected with the organism's environmental niche. Through evolution perception is pre-adapted to detect the significance of things and relationships in space for action. Thus the idea of an affordance introduced in his 1979 work builds upon the basic point that information is available from the environment to directly specify the properties of objects and their relationships. Costall (1981) puts the matter thus;

> *'...we can see that it (the object) is graspable, for example, or can be eaten, or walked upon.'*

The theory of direct perception (Gibson 1966) hypothesises that texture gradients can specify directly either a hole or an edge. Through the hole can be perceived texture or objects in a different plane and hence its existence may be directly perceived. Similarily, the edge of a screen may be perceived by changes in texture etc. specifying seperate planes of depth at the boundary. In this case, the affordance of a hole or an edge may be for the potential action of a detour route. However the affordance of a hole is not necessarily the same as that of an edge. The affordance of a vertical edge in this context might be to reach around. However the affordance of a hole might be to reach through and around. It is possible that there is a developmental sequence in the appearance of the more complex and perhaps more threatening potential action of reaching through a plane surface into an indeterminate space behind. In experiments 1 and 2 infants did not hesitate to reach through the hole in the apparatus to retrieve the object in the Direct condition. However this does not necessarily rule out the possibility that the hole is perceived as offering less affordance for action than the edge.

Although speculative, this does offer an alternative explanation which could be tested experimentally in other spatial contexts. In addition the potential for the perception of motion parallax in the case of the edge as against the hole would be an important factor for the leaning solution discussed earlier. By displacing herself the infant creates motion parallax between the edge of the screen and the object behind (see Figure 2.1. chapter 2). In the case of the hole the same motion parallax is generated but it may be less easy to monitor in relation to the circular boundary of a hole. The visual relationship between a hole and object is inherently more complex than that between a single vertical edge and an object. A more complex and closed boundary must be visually monitored in the case of parallax between an object and a hole.

For all infants in experiments 1,2 and 3, performance on the Direct reaching was at ceiling level. Thus it was demonstrated that detour reaching develops after direct reaching in development. The capacity to perform a functional reach and grasp does not generalise to detour space immediately but there is a substantial developmental time lag between the two abilities. The development of visually guided reaching was traced to the fifth month of life in human infants (McDonnell 1975). Prior to this age, infants are unable to correct inaccurate reaches systematically induced by displacing prisms. However the detour problem indicates that such visually guided reaching may not represent the terminus of the development of eye hand co-ordination. It is suggested here that reaching in a detour space in the case of a true manual detour reach is the product of an internal representation of space in Piaget's sense. The neuro-psychological development which permits this is the development of the distal motor system of eye-hand co-ordination (Moll and Kuypers 1977). However the related inhibition of direct reaching achieved at the neural level hypothesised by Moll and Kuypers would not in itself solve the detour problem for the infant. It is suggested here that the development of associative groups displacement after 1 year of life is an essential component of detour problem solving. Such achievements are the product of a new system combining a spatial system under voluntary cortical control with an motor system practiced at direct tasks and now available to more complex plans. At around 1 year of life reaching is for the first time truly in a represented space.

5:5 Summary

1. In Experiment three, 8 and 10 month old infants were tested on a manual detour task before (Test) and after (Re-test) training by their mothers. Infants were also tested on a Transfer task on the opposite side (left or right) and these Indirect conditions were compared with performance on a Direct reaching task.

2. The experiment aimed to show that the failure of infants in experiment 1 was not due to either right-left movement of the object or the short (15 second) trial time. Previous studies have shown that infants succeed on transparent screen detour tasks at mean age of 10.7 months (Lockman 1984) and 30% of infants between 6-9 months. In experiment 1 and 2 there was almost no success on the task until after 12 months of age.

3. The results showed that infants still failed when given a longer period of time for each trial. The change from left to right (or vice-versa) on the Transfer task did not disrupt performance in this experiment. There was though little success to disrupt. Even after a 5 minute training session given by the mother, 8 and 10 month old infants still failed to retrieve the object in the Indirect task.

4. It was concluded that 8-10 month old infants are unable to solve manual detour problems. The results of experiments 1 and 2 were due to the spatial conditions determined by the apparatus and thus that infants are unable to perform manual detours with a transparent screen until after 12 months of age. It was also concluded that the spatial conditions of other experiments (Bruner 1970; Kaye 1970; Lockman 1984;) were responsible for the abilities demonstrated by some infants before 12 months of age.

5. It was suggested that detour reaching is a characteristic of a higher form of reaching. This may be termed reaching in a represented space. An internal representation of space must be accessed for true manual detour reaching. the detour path itself cannot be physically seen, it must be inferred fromthe perceived relationship between object and screen. Such an

inference implies the existence of an internal spatial system capable of planning associative groups of displacements.

CHAPTER SIX

EXPERIMENT 4: DETOUR REACHING COMPARING PERFORMANCE WITH MIDLINE AND LONG SCREENS IN 9-10, 11-12 and 13-14 MONTH AGE GROUPS.

6.1. Introduction

The previous 3 experiments have established that when a displacement of self action is not available to the infant she cannot solve a visible manual detour problem until at least 13 months of age. However in order to exclude the possibility of such a displacement of self action, the apparatus used provided only for a detour away from the infants midline (by 13 cms.) and the access to that detour path through a hole in the screen. Other procedures have required infants to reach around a vertical edge of a screen (Bruner 1970; Lockman 1984). The apparatus used in this experiment (Figure 6.1.) generated many examples of a displacement of self action. The availability of open space next to the edge of the screen suggested such leaning actions to many subjects. It is possible that such a contour is perceived as what has been termed an affordance (Gibson 1979). On this view what is perceived is the significance of things and spatial relations for the action of infant.

In his study of detour reaching Bruner (1970) used an apparatus which provided for detour spaces at the midline and across the midline (as well as opaque screens not investigated here). In addition Bruner varied the relationship between the object and the edge of the screen. For some conditions the object was placed just in from the edge of the screen. For deep conditions the object was placed around 10 cms. in from the edge of the screen. The variety of conditions enabled Bruner to conclude that the behavioural space within which the infant operates expands with age. There is evidence to support the importance of the midline in early spatial development (Bruner 1972). The gradual expansion of possible action outwards from the midline might be related to the maturation of structures subserving focal and peripheral vision (Trevarthen 1968).

Thus a central question that must be addressed is whether this expansion of behavioural space represents the gradual generalisation of detour knowledge with age or experience (or both). An alternative possibility is that the results show an increase in the possibility of a displacement of self action with the screen and object nearer the infant's midline. It would be physically more difficult to lean around a screen placed across the midline than a screen with the edge at the midline (see Figure 2.1. chapter 2). Of course in such a case, it could also be possible that leaning space increases with age just as detour space does.

The first trial in which an infant is successful is crucial to the argument that infants 12 months old and younger are unable to solve detour problems manually. On this argument such infants might solve the problem by displacing the self to enable a line of sight solution. If on the first successful trial the infant used a displacement of self action then on subsequent trials a purely manual strategy might be possible. Piaget observed (Piaget 1954) that infants are able to solve a detour by following the trajectory of the displacement prior to the full development of associative groups. In this experiment and in experiments 1,2 and 3 the procedure excluded this possibility. The experimenter placed the object behind the screen via a trajectory the infant could not copy. However having succeeded using a displacement of self strategy, the infant has only to repeat the overall displacement with her hand to execute the purely manual solution. This means simply following her own displacement. That such a succession of actions is possible is of empirical and theoretical interest. If such were a typical observation, then it might constitute a mechanism for the construction of associative displacements. Hence the important analysis is of the first successful response. If infants show the displacement of self action on their first successful trial this is strong evidence that a reversible displacement mechanism precedes associative displacements in the solution of detour problems.

The aims of this experiment were threefold. First to establish whether reported success on detour problems prior to 12 months of age (Bruner 1970; Lockman 1984) was due to the adoption of a displacement of self action. Examination of responses would permit the importance of this in the origin of detour problem solving to be ascertained. The second aim was to establish whether the behavioural space within which the infant operates increases with age as reported by Bruner (1970). The third aim was to establish whether the reported delay between solving manual and locomotor detours in a longitudinal experiment (Lockman 1984) could be demonstrated in a cross-sectional study. The experiment was thus done in two parts, the manual and the locomotor test in the same session or at most within one week. The comparison between manual and locomotor spaces is reported and discussed in chapter 7.

6:2 Method

Subjects

Subjects were recruited in the same way as experiments 1,2 and 3. Subjects were 48 infants, with equal numbers of each sex, divided into three age groups: 9-10 months, 11-12 months and 13-14 months old.

Group 1: 16 infants, mean age = 315.5 days, S.D. = 17.3 days (age range 282 days-332 days).

Group 2: 16 infants, mean age = 364.4 days, S.D. = 17.4 days (age range 334 days-1 year 24 days).

Group 3: 16 infants, mean age = 1 year 65.6 days, S.D. = 19.3 days (age range 1 year 33 days-1 year 91 days)

Six infants aged 282 , 288 , 324, 329, 332 days and 1 year 13 days were excluded because they fussed and failed to complete the experiment. Because of attrition of the sample across the two parts of the experiment (manual and locomotor detours) infants who failed to complete the locomotor part of the experiment reported in chapter 7 were included here as long as they completed the manual detour test. The exclusion of these subjects would have biased the sample against less competent crawlers and walkers.

Apparatus

The apparatus comprised a low chair and a seperate moveable stand on which the detour apparatus was mounted. The detour apparatus (see Figure 6.1.) consisted of a box, (90cms. wide × 46cms deep × 46cms. high), which was open at the top and back to enable video-filming of the subject. The floor of the box was covered with green baize and the remainder of the apparatus was painted light grey. At the front of the box was mounted a transparent screen, which could be moved laterally to partly cover a rectangular hole in the box (46cms. wide × 26cms. high).

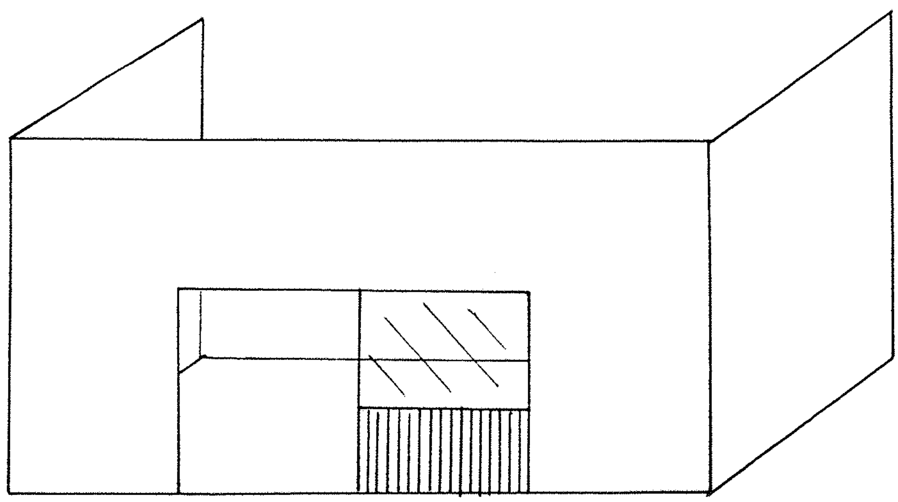


Figure 6.1.

Detour Test Apparatus Used in Experiment 4

Two distinct positions were investigated in this study for both left and right screens. In the Midline screen condition, the edge of the transparent screen was placed at the midline, either left or right of the infant. In the Long screen condition, the edge of the transparent screen was placed 20cms. across the midline, either left or right. Vertical black stripes were applied to the screen using letraset to a height of 11cms. as in experiment 1. This enabled the subject to see the screen clearly as in experiments 1 and 2.

The object used was the same as in experiments 1 and 2. For the Direct open condition it was placed 3cms. behind the aperture created by the edge of the screen. For the Indirect conditions 1 and 2, the object was placed 3cms. behind the screen and 3cms.(1) and 20cms.(2) respectively in from the edge of the screen. Thus there were 12 positions of the object and screen relative to the subject, left or right, long or midline screen and positions 0 (open) 1 and 2.

Design

A 'within' subjects design was used, each infant acting as its own control. Infants received 12 trials, 1 of each possible combination of screen and object position. Infants received all their trials either in the order 0,1,2 (out-in) or 2,1,0 (in-out). The other independent variables were counterbalanced, sex of subject, screen order, (Long screen : Midline screen) and side of starting, (left : right).

Scoring

The video-film of each infant was carefully examined and scored for according to the same categories as experiments 1 and 2. The measures used in the analyses were success and failure at retrieving the object. In addition, it was noted when an infant leaned around the screen and whether this was synchronised with an attempted reach. Two categories of successful reaching were thus devised for Indirect conditions. These were the displacement of self solution and the manual detour solution. A third ambiguous category was identified when an infant leaned around the edge of the screen prior to a successful reach but not synchronised with the successful reach. These were recorded, but as the infant still had to perform a manual detour it was not possible to identify the status of this behaviour.

Inter-observer reliability

A second independent scorer viewed video-film of 10% (5) of the subjects to the establish the reliability of the experimental data. For the categories of Success divided into the 3 sub-categories of type of success or Failure, agreement was reached on 58/60 trials (97%).

6.3. Results

Direct conditions

Inspection of Table 6.1. shows that all infants succeeded at the Direct task with the object in the open position (0). This was not surprising as each trial continued until a point of success or 30 seconds without advance. Thus the comparison between Midline and Long screens for the open object position inevitably gives no variance to be analysed (t=0, 1df, n.s.) for each age group. Direct reaching was thus at ceiling level and this accorded with the results of experiments 1,2 and 3. Given a long period up to 30 seconds without progress this was not surprising. Failure would have indicated abnormal development or loss of motivation. Importantly the infant subjects were as successful given different locations of the object left or right, and away or at the midline. Thus reaching space in the Direct conditions did not show the expanding behavioural space reported by Bruner (1970) for detour space.

Indirect conditions

The data were pooled across (a) left and right screens within subjects to provide a score out of 2. Other counter-balanced variables which did not contribute significantly to success were (b) sex of infant ,(c) order of object position, (d) side of starting. None of these variables contributed significantly to success: (a) left mean = 1.21; right mean = 1.19 ((paired t test)t=0.03, 47df, n.s.), (b) Male mean = 1.35; Female mean = 1.04 (t=1.53, 46df, n.s.), (c) 0,1,2 mean = 1.20; 2,1,0 mean = 1.20 (t=0, 46df, n.s.) (d) Left-Right mean = 1.14; Right-Left mean = 1.26 (t=0.61, 46df, n.s.).

TABLE 6.1. Experiment 4 (Summary Table)

Mean Score of Successful Retrieval of Object Out of 2 trials

	(n)	Indirect				Direct (0)	
Screen		Midline		Long		Midline	Long
Total	(48)	1.34		1.06		2.00	2.00
×Age							
10m	(16)	0.91(46%)		0.41(21%)		2.00	2.00
12m	(16)	1.31(66%)		1.22(61%)		2.00	2.00
14m	(16)	1.81(91%)		1.56(78%)		2.00	2.00
Object×Screen		1	2	1	2		
Total		1.52	1.17	1.10	1.02		
×Age							
10m	(16)	1.13	0.69	0.44	0.38		
12m	(16)	1.50	1.13	1.31	1.06		
14m	(16)	1.94	1.69	1.56	1.56		
Object		1		2		0	
Total		1.31		1.09		2.00	
×Age							
10m	(16)	0.78		0.53		2.00	
12m	(16)	1.41		1.13		2.00	
14m	(16)	1.75		1.63		2.00	
Order		Long-Midline		Midline-Long		M-L	L-M
	(24)	1.01		1.38		2.00	2.00
Order		0-1-2		2-1-0		0-1-2	2-1-0
	(24)	1.20		1.20		2.00	2.00
Order		Left to Right		Right to left		L-R	R-L
	(24)	1.14		1.26		2.00	2.00
Sex		Male		Female		M	F
	(24)	1.35		1.05		2.00	2.00
Side		Left		Right		L	R
	(48)	1.21		1.19		2.00	2.00

All scores are mean scores out of 2.

Figure 6.2. Experiment 4

Graph Showing % Success in Indirect and Direct Trials

Comparing Deep (2), Edge (1) and Open (0) Object Positions

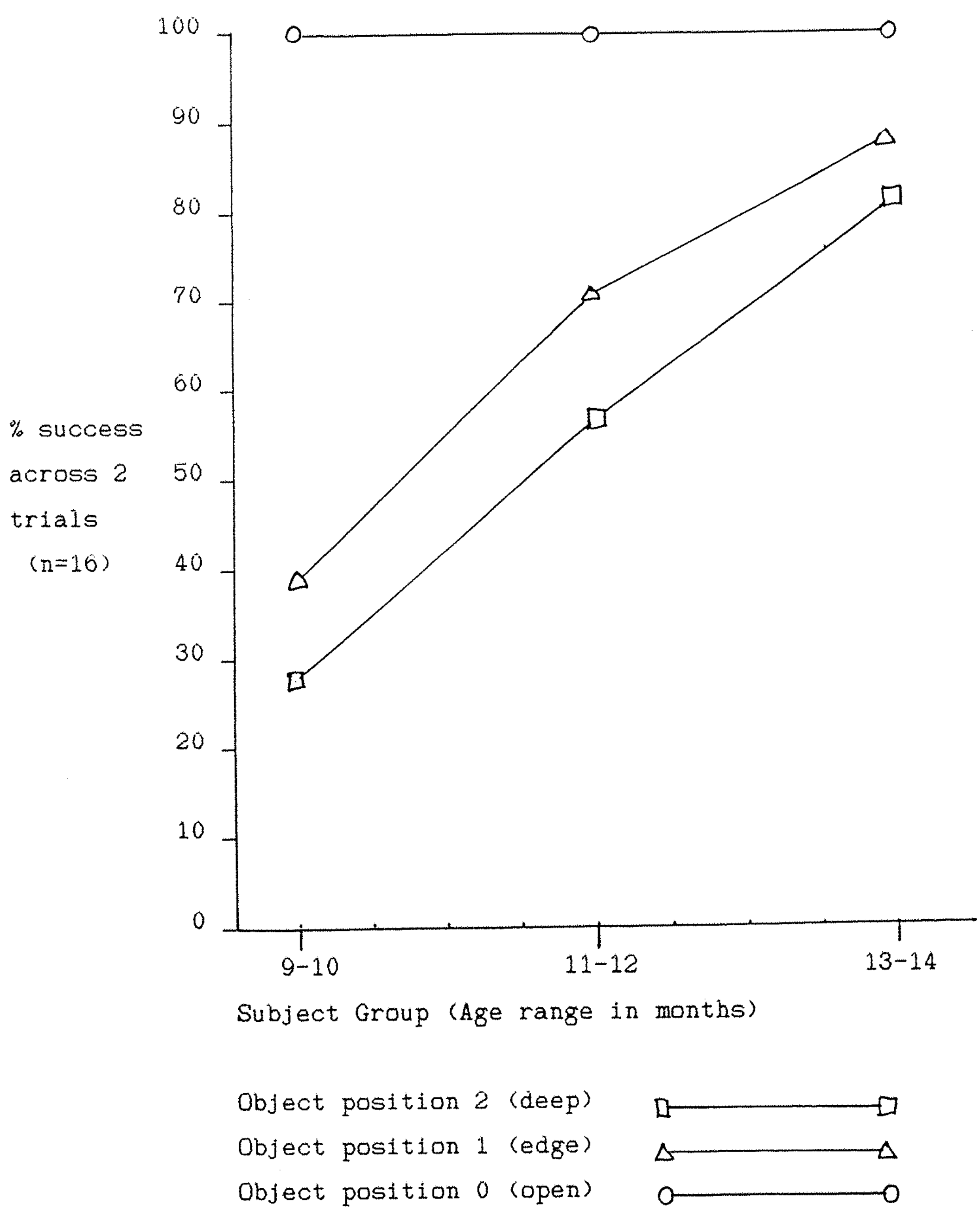
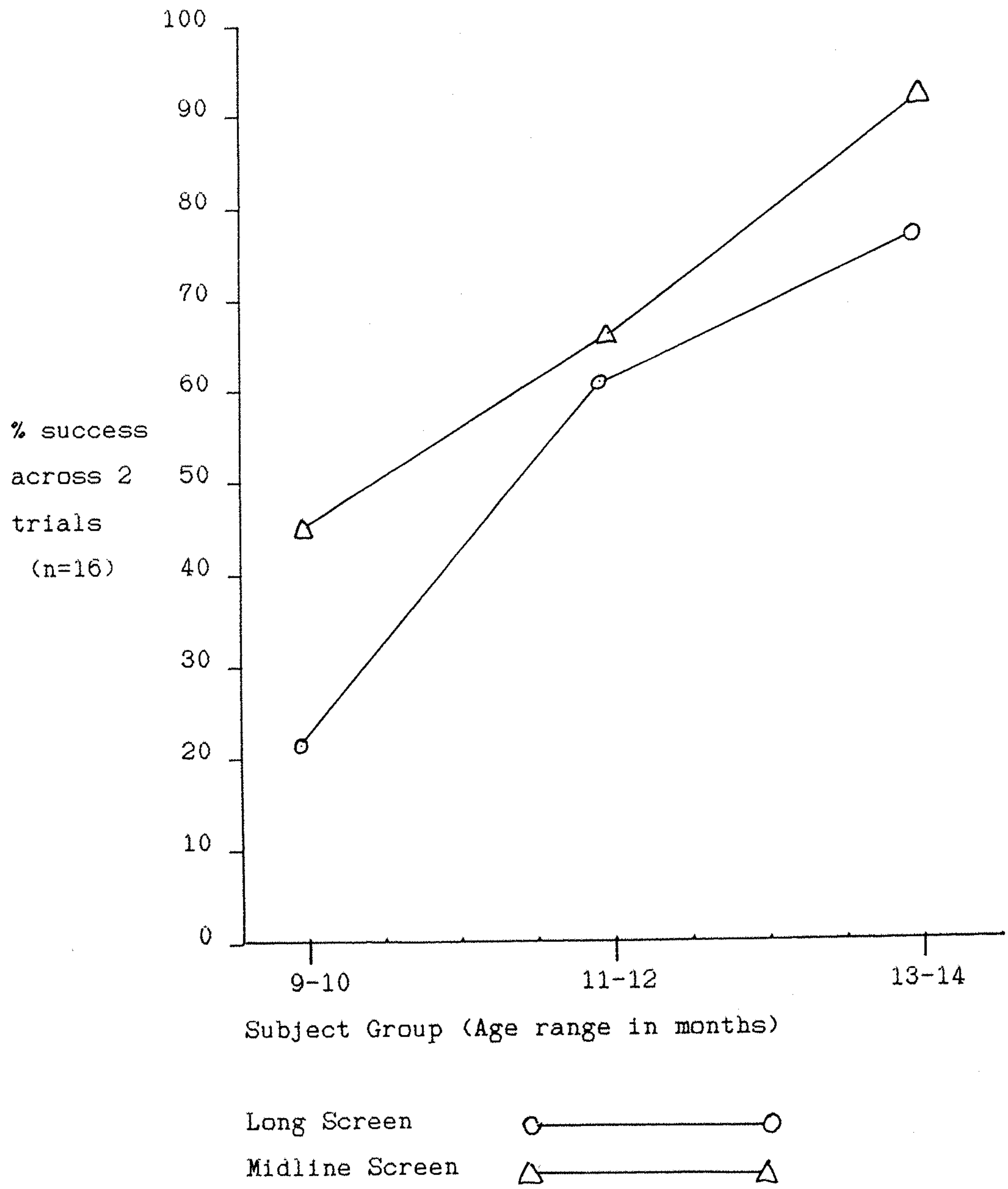


Figure 6.3. Experiment 4

Graph Showing % Success in Indirect Trials

Comparing Long and Midline Screen Positions



The other order variable, Screen length was significant on a 1 tailed test: Midline-Long mean = 1.38; Long-Midline 1.01 (t=1.90, 46df, p<.05). This showed that initial experience on Midline screens enhanced performance overall. In order to see which age groups contributed to this result, t tests were performed on results for each age group. Only the 9-10 month group showed a significant effect: 9-10 month M-L mean = 1.00; L-M mean = 0.31 (t=2.14, 14df, p<.05). 11-12 month M-L mean = 1.47; L-M mean = 1.03 (t=1.48, 14df, n.s.). 13-14 month M-L mean = 1.69; L-M mean = 1.69 (t=0, 14df, n.s.). These results show that the 9-10 month age group show enhanced performance with Midline screens first. Older infants showed no significant effect of screen order. This effect may be due to a learning effect across trials. Learning the detour on Midline screens may transfer to Long screens. Performance on Long screens, being at a lower level may not show such positive transfer effects to Midline screens. Bruner (1970) did not find these order effects because screen length was a between subject variable in his detour reaching experiment.

The data was subjected to Analysis of Variance (Table 6.2.) with length of screen and position of object relative to screen as within subject variables and age as the between subjects variable.

Age was a significant source of variance (F = 13.24, df 2.45, p<.001). Pairwise comparisons of age groups were performed using Scheffe's method, testing F ratios against F'= 2F. These comparisons revealed a significant difference between 10 month and 14 month infants (F=8.12. df 1,45, p<.05.). Other pairwise comparisons showed no significant differences between; 10 month and 12 month (F=2.98, df 1,45, n.s.) and 12 and 14 month (F=1.41, df 1,45, n.s.). Thus there was a significant increase in successful response over the age range 9-10 months to 13-14 month.

The effect of screen length was significant (F=8.26, df 1,45, p<.01). Inspection of Table 6.1. shows the mean success rates were; Long mean = 1.06 and Midline mean = 1.34. Thus Midline screens were significantly easier than long screens. The effect of object position relative to the screen was also significant (F=9.2, df 1,45, p<.01.). Inspection of Table 6.1. shows the mean success rates were; position 1 = 1.31, and position 2 = 1.06. Thus infants found the object easier to recover from behind the screen when it was nearer the edge of the screen. However none of the interactions were significant and hence the hypothesis that younger infants found shorter paths relatively easier than older infants was rejected.

TABLE 6.2. Summary of Analysis of Variance Experiment 4

Source of Variance	Sum of Squares	d.f.	Mean Square	F Ratio	p
Age	34.41	2	17.21	13.24	p<.001
Residual 1	58.42	45	1.30	-	-
Screen	3.80	1	3.80	8.26	p<.01
Age×Screen	1.38	2	0.69	1.50	n.s.
Residual 2	20.57	45	0.46	-	-
Object position	2.30	1	2.30	9.20	p<.01
Age×Object position	0.21	2	0.11	0.44	n.s.
Screen×Object position	0.88	1	0.88	4.00	n.s.
Age×Screen× Object position	0.04	2	0.02	0.09	n.s.
Residual 3	9.83	45	0.22	-	-
Total	143.08	191	-	-	-

Analysis of Displacement of Self Actions

Table 6.3 shows the number of first successful trials in which infants used the displacement of self action compared with the manual detour solution. Inspection of Table 6.3, shows that overall 43 infants were successful at least once in Indirect trials. 22 out of these successful subjects used a displacement of self action synchronous with that success. These infants did not have to perform a manual detour reach since they resolved the problem into a direct reaching solution by their leaning displacement. Of these infants, none of the 3 age groups showed a significant proportion using this action. However, additional infants performed a displacement of self prior to (but not synchronous with) a successful manual detour. These ambiguous cases were few in number and are a statistically small proportion. If they are included with synchronous displacements only 2/11 9-10 month old infants show a true manual detour reach. This is a significantly low proportion as shown in Table 6.4 (binomial $p=.03$). It is of course possible that such infants may have learned to do a manual detour by leaning around the screen. It is not possible to evaluate this hypothesis here though.

A χ^2 test was computed to compare the relative proportions of displacement of self action and manual detour solutions with age. This showed there was no significant transition with age ($\chi^2=2.17$, 2df, n.s.) in the frequency of this action. It could not therefore be asserted that displacements of self were more frequent on the first successful trial with younger infants.

There was evidence that a high proportion of successful first responses were achieved through a displacement of self action. It is not possible to assert that these infants could not achieve a true manual detour reach initially. To further investigate the possible learning effects, analysis of the subsequent successful trials of infants was undertaken. A binomial test was used to compare:

a. infants who succeeded initially by displacement of self and subsequently by a true manual detour reach, with

d. infants who succeeded only by displacement of self.

This analysis showed that a significant proportion of infants who used a displacement action synchronous with a first successful reach went on to succeed using a true manual detour; a=15, d=5 (binomial p=.021). Broken down by age group this analysis showed that only in the oldest group did a significant proportion go on to solve the problem by a true manual detour from the initial displacement of self action; 9-10 month a=4, d=3 (binomial p=.5); 11-12 month, a=4, d=4 (binomial p=.637); 13-14 month, a=7, d=0 (binomial p=.008). The hypothesis that the displacement action leads to a successful manual detour without a displacement was only confirmed in the oldest group.

It was noted that 7 infants (b) performed synchronous displacement actions in trials after successful manual detours . In comparison with this group infants in (a) above failed to demonstrate a significant direction to the hypothesised learning; a=15, b=7 (binomial p=.067). Thus it could not be asserted that learning was only in the hypothesised direction from displacement of self solutions to purely manual solutions.

Finally a comparison was made of the relative proportions of Long and Midline screen trials solved using the displacement of self solution on the first successful trial. This analysis showed that such solutions were significantly more likely on Midline (M) than Long (L) screen trials; M=19, L=3 (binomial p<.001). Broken down by age group only the 11-12 month age group failed to show a significant effect of screen length on the proportion of such displacement of self actions.9-10 month, M=7, L=0 (binomial p=.008); 11-12 month, M=5, L=2 (binomial p=.227); 13-14 month, M=7, L=1 (binomial p=.035).

These results are then equivocal concerning the hypothesis that a displacement of self action leads to advance to true manual detour reaching and possibly to true associative groups of displacement. They do however provide strong evidence for the hypothesis that a leaning strategy is more frequent with midline screens. This was a major factor contributing to success at solving the detour problem in all age groups although it failed to reach significance in the 11-12 month age group.

TABLE 6.3. Experiment 4

Number of Infants Using a Displacement of Self (Leaning) Strategy in the Indirect Condition

Age in months	10m	12m	14m	Total
No. of Infants leaning round the screen at least once.	* 12/16	* 14/16	* 11/16	*** 37/48 z=3.61
Displacement synchronous with first success	7/11	8/16	7/16	22/43
Displacement before first success (within trial).	* 2/11	** 2/16	*** 0/16	*** 4/43 z=5.18
No displacement before or synchronous with first success. (true manual detour reach)	* 2/11	6/16	9/16	17/43 z=1.22
Total Successful on at least one trial.	11/16	*** 16/16	*** 16/16	*** 43/48 z=5.34

* Statistically significant at p<.05 binomial test.
** Statistically significant at p<.01 binomial test.
*** Statistically significant at p<.001 binomial test.
(z test used where N>24). 1 tailed probabilities used

6.4. Discussion

Experiments 1, 2 and 3 showed that infants were unable to solve a simple manual detour problem prior to at least one year of age. In this study success was at a level comparable to other experiments involving detour reaching problems (Bruner 1970; Lockman 1984). This may be accounted for in large part by the displacement of self action which Table 6.4. shows was performed by the majority of subjects at sme stage in the Indirect trials.

The characteristic lean around and then reach in directly sequence was shown by approximately half of the subjects on their first successful trial. This raises the question of whether such a sequence is planned. It might be that infants lean around without any stategic intention to reach in after. Alternatively, the infant may plan the sequence. In the latter case she would have demonstrated the associative group of displacements characteristic of stage V (Piaget 1954). It is not possible to distinguish these two possibilities without further research. However it was observed that after leaning around the screen, some infants reached in to retrieve the object very rapidly. Others, although fewer in number leaned around and then simply reversed their action back again. On Piaget's theory the stage IV infant (approximately 8-12 months) discovers the reversible operation and this may be exactly what some infants in this study were doing.

The stage IV secondary circular reaction is characterised by the repetition of schemes of action in new situations. Piaget emphasises the recognition of what he termed 'signs' at this level. An example of a sign is the cover over an object in the hiding task which stage IV infants are able to remove. The cover is only a sign, signalling the presence of the object. In the case here, the infant may have learned that an edge is a contour which is a sign of a potential event contingent upon her action. The view of Gibson (1979) that what is perceived is affordance for action would not seem to be too dissimilar from this idea (although the developmental route to the discovery of signs or affordances is distinct). The point is that an edge may be perceived as a sign for a detour route and that this is learned during stage IV by the displacement of self around contours and edges of barriers. Only later in stage V does the sign become perceived as permitting the true associative group of displacements characterised by detour reaching without leaning. Hence on the perspective adopted here, the results of experiment 4 are consonant with Piaget's theory. The displacement of self is only a stepping stone to true associative displacements if at all. The evidence that such displacements of self may lead to true manual reaching was equivocal. Clearly experimental manipulations could be devised to examine the relationship between the two forms of solution.

The finding that both screen position and object position were significant sources of variance confirmed the results of a previous study (Bruner 1970). The reasons for these results though may be related to the displacement of self action. This was shown to be far more common for Midline screens than Long screens. Consider the unexpected discovery of an order effect with Midline screens first. Such transfer from Midline solutions to Long screens may itself derive from the high proportion of successful displacement of self actions with Midline screens.

The results of this experiment are consistent with the neuro-psychological hypothesis that the distal reaching system matures later than the proximal. The development of the displacement of self action would not require the immature distal structures for its enaction. The development of reaching in a represented space may be related this displacement of self. Indeed adopting the position of K. Gibson (1981) the interaction between neuro-ontogeny and the infants environmental experiences may be crucial for the maturing nervous system.

6.5. Summary

The aims of experiment 4 were to investigate the spatial conditions under which infants can perform detours in a reaching space. Bruner (1970) has demonstrated that infant performance in such tasks shows a developmental trend. In particular he showed that the behavioural space within which infants could solve detour problems expands with age. It was however possible that infants might use a displacement of self action leading to a solution by a direct reach. Such actions do not necessarily indicate the availability of associative groups of displacements thought to be necessary for such a competence. This aspect of behaviour was investigated in this study

2. In experiment 4 three groups of infants aged 9-10 months, 11-12 months and 13-14 months were tested on a Direct and Indirect reaching task. This test used a new apparatus which permitted investigation of spatial variables and encouraged a displacement of self or leaning action. The screen which was transparent was placed at the Midline or across the infants midline in the Long screen position. The object was placed in the open space for the Direct condition (0). For the Indirect conditions the object was placed either behind the edge of the screen (1) or 20cms. in from the edge of the screen.

3. The results showed that Direct reaching was at ceiling level both at the midline and at the periphery. Thus behavioural space for direct reaching was shown to be mature at all age levels investigated. For the Indirect task the results showed that Midline screens were easier than Long screens. Deep object positions (2) were also more difficult than edge positions (1). These two spatial variables did not interact however. There was an overall developmental trend but not in interaction with object position or screen position.

4. The analysis of displacement of self actions gave some evidence that these contributed significantly to success in the 9-10 month age group. Overall the majority of infants used such an action at some stage in the experiment. In particular the infants used this action to solve the problem with midline

screens. The evidence concerning progression from a displacement of self strategy to purely manual solutions was equivocal.

CHAPTER SEVEN

EXPERIMENT 5: PERFORMANCE ON A LOCOMOTOR DETOUR TASK in 9-10, 11-12 AND 13-14 MONTH AGE GROUPS SPATIAL VARIABLES AND THE COMPARISON WITH A MANUAL DETOUR PROBLEM

7.1. Introduction

The problem posed by the locomotor detour problem in this experiment is on the surface isomorphic with that in manual space. Reference to Figure 7.1. indicates the structure of the problem. The subject (S) at L or M must locomote to 0 the edge (E) and can then locomote directly to the goal object (O) at 1,2 or 3. The displacements required are identical to those required in the manual detour problems investigated in experiments 1-4. The displacements required form a group structure SE + EO = SO as described by Piaget (1954). Piaget's analysis describes these displacements as constituting the associative group and these develop during stage V (roughly 12-18 months for visible detour spaces.

Comparison with the task demands of the manual problem is though more complex than appears to be the case initially. The manual problem (see Figure 2.1. chapter 2) has been shown to have at least two possible solutions. The true manual detour requires the infant, staionary at S to reach to E the edge of the screen and then in to O the object. However as demonstrated in experiment 4, infants frequently lean around the screen performing the displacement SE by adjusting their posture. The remaining displacement EO is now a direct reach which can be visually guided without knowledge of detours. A brief consideration of the locomotor detour problem in Figure 7.1. shows that such is inevitably the case. Having locomoted from S to E the infant now has only a direct displacement from E to O to perform. Hence the locomotor problem solution is inherently different from the true detour reaching solution. It is inevitably a displacement of self action.

As this is the case, it is also true that depending on the relationship between O and the screen, motion parallax is under suitable conditions provide cues to give perceptual support to a displacement action SE. It follows from this analysis that predictions concerning the relationship between solutions to detour problems in reaching and locomotor space are frqught with difficulties. The only available evidence on the developmental relationship between reaching and locomotor detour problems indicates that reaching problems are solved earlier than locomotor ones (Lockman 1984). This was true with opaque barriers as well as transparent ones. This supports the hypothesis that with more reaching experience in near space than locomotor experience in distant space, reaching ability is more highly developed in the infant. Piaget (1954) proposed that the distinction between near and far space is only abolished with active locomotor experience.

Spatial variables may also be important in locomotor detour problems. Lewin (1936) hypothesised that the angular disparity between subject, barrier and object would affect performance. He observed difficulty in solving detour problems where the infant had to turn away 180° from the object to access a detour path. Lockman systematically varied the position of the barrier and the position of the object in a longitudinal experiment with a transparent barrier. He found no effect of these manipulations. Infants solved all spatial configurations in the same session. However the space that Lockman tested his subjects in was relatively small. The barrier was 106 cms. wide × 74 cms. high. The infant was seated immediately in front of the barrier and object and infant were either at the midline of the screen or close to the edge. It is possible that in a larger space varying the disparity of the subject and object in relation to the edge of the barrier may generate the effects noticed by Lewin. In the extreme case where the subject must turn away from the goal, the problem becomes qualitatively different. If the subject cannot perceive the entire detour path in the immediate visual field then the problem may be equivalent to a problem in with an opaque barrier. In the study reported here, the entire situation was potentially available to the subject in the visual field.

As Lockman (1984) pointed out, the locomotor space may be more difficult because a larger space needs to be represented if a solution based on a mental representation is to be produced. However the empirical evidence does not support this hypothesis. Lockman showed that varying the starting position of the subject and hence the length of the detour path had no effect on performance. This study aimed to test this hypothesis in larger space with all dimensions scaled up. The study further tested the hypothesis that reaching detours are solved earlier than locomotor ones. Lockman demonstrated this in a longitudinal study but it would be a more reliable finding if this could be demonstrated with naive subjects in a laboratory based cross-sectional experiment. Lockman visited all of his subjects at home. In the home environment, familiar landmarks may give cues to infants in solving detours. In a laboratory setting such cues can be minimised and standard conditions produced. There are of course advantages to studying infants in the home. However as has been argued earlier for manual detour problems the ability to solve a detour task under certain circumstances does not prove that the infant can generalise her ability in all circumstances.

7.2. Method

Subjects

48 infants served as subjects. They were divided equally by sex and into 3 age groups. These were 9 and 10 months (n=16), 11 and 12 months (n=16) and 13 and 14 (n=16) months old.

Group 1: 16 infants (8 male, 8 female), mean age = 320.1 days, S.D. = 17.7 days, (age range 295 days - 332 days).

Group 2: 16 infants (8 male, 8 female), mean age = 1 year 1.6 days, S.D. = 16.9 days, (age range 334 days - 1 year 24 days).

Group 3: 16 infants (8 male, 8 female), mean age = 1 year 65.1 days, S.D. = 20.8 days, (age range 1 year 33 days - 1 year 90 days).

Ten infants aged 288, 293, 304, 314, 324, 329 days and 1 year 13 days, 1 year 38 days and 2 aged 1 year 20 days were excluded from the experiment. Of these, 3 infants were unable to locomote effectively in an independent fashion. The other 7 fussed and did not complete the required number of trials. The attrition rate is high because half the infants had performed the manual task in experiment 4 before the locomotor task in this experiment.

Apparatus

The apparatus comprised a wooden playpen type barrier (1.2m high, 2.4m wide) constructed of wood and painted light grey. The barrier was placed in the laboratory which was 4.3m long x 3.6m wide. It was plain with a beige coloured carpet.The barrier was placed across the centre of the rectangular laboratory from either the left or right wall (see Figure 7.1.). Thus the barrier extended 2.4m. out left or right from the wall. The 'object' in this study was the mother who sat on a chair and held an attractive toy, usually a brightly coloured plastic duck. The mother was used because she had to remain with the infant and hence with an attractive toy for a lure, she provided a convenient goal for the infant. McKenzie and Bigelow (1986) adopted a similar goal in their experiments.

The infant was video filmed from a camera mounted on the wall shown in Figure 7.1.. The camera was operated by remote control from an adjacent room. In practice it was not moved during trials but only for left and right barriers, a between subjects variable.

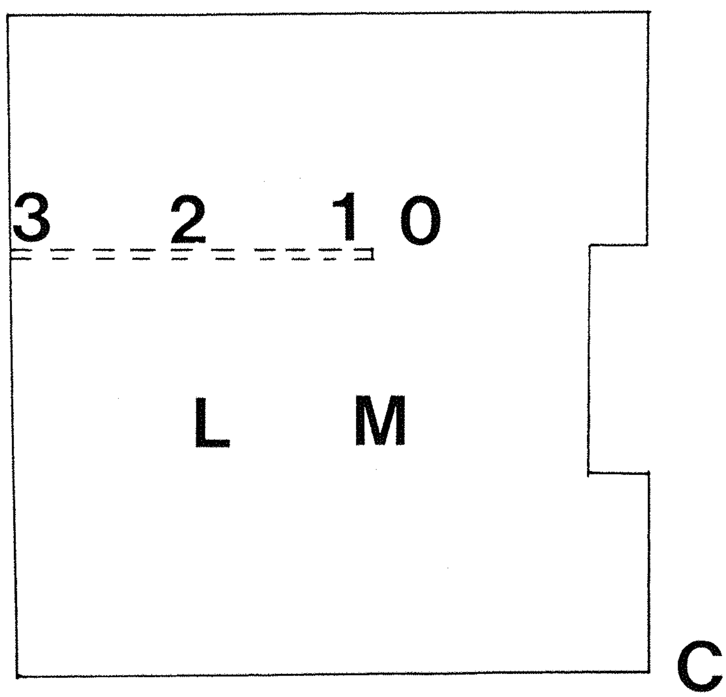


FIGURE 7.1.

Layout of the Experimental Room with the Detour Barrier on the Left of the Infant.

The positions of the object (0,1,2,3) and the subject for Long (L) and Midline (M) screen positions are shown.

Procedure and Design

Each infant received a total of 8 trials. Infants received all their trials with the screen either on the right or left. For the Long barrier condition, the infant started the test from a position 1.2m perpendicular from the barrier and 1.2m in from the edge of the barrier. For the Midline barrier condition, the infant started the test opposite the edge of the barrier and the same distance away from the barrier as in the long screen condition.

The position of the mother was on the opposite side of the barrier from the infant. She was always sat 0.3m back from the barrier. For the open condition, the mother sat 0.3m out from the edge of the barrier in the opening between the barrier and the laboratory wall. For conditions 1, 2, and 3, the mother sat 0.3m, 1.2m and 2.4m in from the edge of the barrier. Thus there were 8 positions of mother and barrier relative to the infant, long or midline barrier, and positions 0 (open), 1, 2 and 3.

Infants received all their trials either in the order 0,1,2,3,(out-in) or 3,2,1,0 (in-out). Thus the between subject variables were side of barrier, order of mother's position and order of screen length (long-short or short-long). Within subject variables were barrier and mother position. Side of trials (left or right), order of trials, (in-out or out-in) and length of barrier (long or midline) were counter-balanced across subjects within groups.

During a 10 minute period in the room adjacent to the test room the infant was familiarised with the experimenter while the instructions were explained to the mother. During this period the infant's interest was aroused in a toy, which the mother subsequently used to lure the infant to her. The mother then took her place on the chair while the experimenter placed the infant on the starting position facing the opening. The mother encouraged the infant to come to her verbally and by showing the toy. The trial continued until the infant reached the mother or until 30 seconds elapsed with no progress. Trials were terminated if the infant became distressed. Following each trial the mother stood up and picked up her infant. If infants failed the detour, they were passed to their mother over the barrier. The experimenter then moved the chair to the position of the next trial from the opposite side. The mother then passed the infant to the experimenter over the barrier. She sat down and the infant was placed back at the starting position. This procedure was repeated until all 8 trials were finished

Scoring

The video film of each infant was carefully examined. A route map for each trial was plotted using a scale of 1:30. This was achieved by constructing a template of the projection of the room space onto the video screen. The measure used in the analysis was a simple success or fail. It was also noted for each trial, the infants form of locomotion (crawling or walking). Further notes were made if the infant used the bars of the barrier to pull themselves up or tried to reach through the bars to the mother.

Inter-observer reliability

The video-films of 10% (5) infants were examined by an independent judge and scored according to the criteria above. On the measure used in the analysis agreement was reached on 37/40 trials 93%.

7.3. Results

Performance on Direct trials

This was at ceiling level for all age groups. The infant subjects who did not succeed on particular trials appeared to be involved in exploratory activities.

Performance on Indirect trials

The percent success rates for each age group are depicted in the graph in Figure 7.2. As can be readily seen the performance of even the 9-10 month age group was at a high level (45% success rate). This accords with the figure given by Lockman of a mean age of success of 10.6 months.

The data were scored 1 for success and 0 for failure. There were no significant differences between sex of subject: Male mean = 0.70; Female mean = 0.73 (t=0.33, 46df n.s.) or side of barrier; Left mean = 0.73; right mean = 0.70 (t=0,33, 46df n.s.).

An Analysis of Variance was performed with age as the between subject variable and barrier length and position of mother as within subject variables. Lunney (1970) has shown that this type of analysis of dichotomous data is robust where there are at least 40 degrees of freedom.

The Analysis of Variance (Table 7.2) showed age to be a significant source of variance (F=7.68, df 2,45, p<.01). Pairwise comparisons of age groups using Scheffé's procedure showed a significant difference between the 10 and 14 month age groups (F=14.59, df 1,45, p<.01). The other comparisons were not significant 10 and 12 month (F = 7.10,d.f. 1,45, n.s.) and 12 and 14 month (F=1.33, df, 1,45 , n.s.).

The length of the barrier was not a significant variable (F=0.93, df 1,45, n.s.). The position of the mother proved highly significant (F=11.94, df 2,90, p<.001). Pairwise comparisons of positions 1,2 and 3 showed 1 and 2 differed significantly (F=8.74, df 1,90, p<.05) and 1 and 3 differed significantly (F=23.41, df 1,90, p<.001). The comparison between positions 2 and 3 showed no significant difference (F=3.54, df

1,90, n.s.). This indicated support for the hypothesis that representation of a larger space was more difficult. There was no interaction with age though and hence object position effect does not have a developmental character within the age groups studied in this experiment.

TABLE 7.1. (Summary Table)

Mean Success Rate per Trial on the Locomotor Task

	(n)	Indirect			Direct	
10m	(16)	0.45			0.91	
12m	(16)	0.76			0.94	
14m	(16)	0.90			1.00	
Total	(48)	0.70			0.95	
Screen Position		Long (L)	Midline (M)		L	M
10m	(16)	0.46	0.44		0.88	0.94
12m	(16)	0.75	0.77		0.94	0.94
14m	(16)	0.83	0.96		1.00	1.00
Total	(48)	0.68	0.72		0.94	0.96
Object Position		1	2	3		
10m	(16)	0.63	0.41	0.31		
12m	(16)	0.81	0.78	0.69		
14m	(16)	0.97	0.88	0.84		
Total	(48)	0.80	0.69	0.61		

Side of Screen	L	R
(24)	0.73	0.69

Sex of Infant	M	F
(24)	0.69	0.73

All scores are mean scores out of 1.

TABLE 7.2. Summary of Analysis of Variance Experiment 5

Source of Variance	Sum of Square	d.f.	Mean Square	F Ratio	p
Age	10.13	47	5.07	7.68	<.01
Residual 1	29.52	45	0.66	-	-
Screen	0.13	1	0.13	0.93	n.s.
Age×Screen	0.27	2	0.14	1.00	n.s.
Residual 2	6.27	45	0.14	-	-
Object	1.72	2	0.86	11.94	<.001
Age×Object	0.47	4	0.12	1.67	n.s.
Residual 3	6.48	90	0.07	-	-
Screen×Object	0.01	2	0.005	0.09	n.s.
Age×Screen×Object	0.34	4	0.09	1.55	n.s.
Residual 4	4.98	90	0.06	-	-
Total	60.32	287	-	-	-

Figure 7.2. Experiment 4

Graph showing % Success in Direct and Indirect Conditions Across the Age Groups

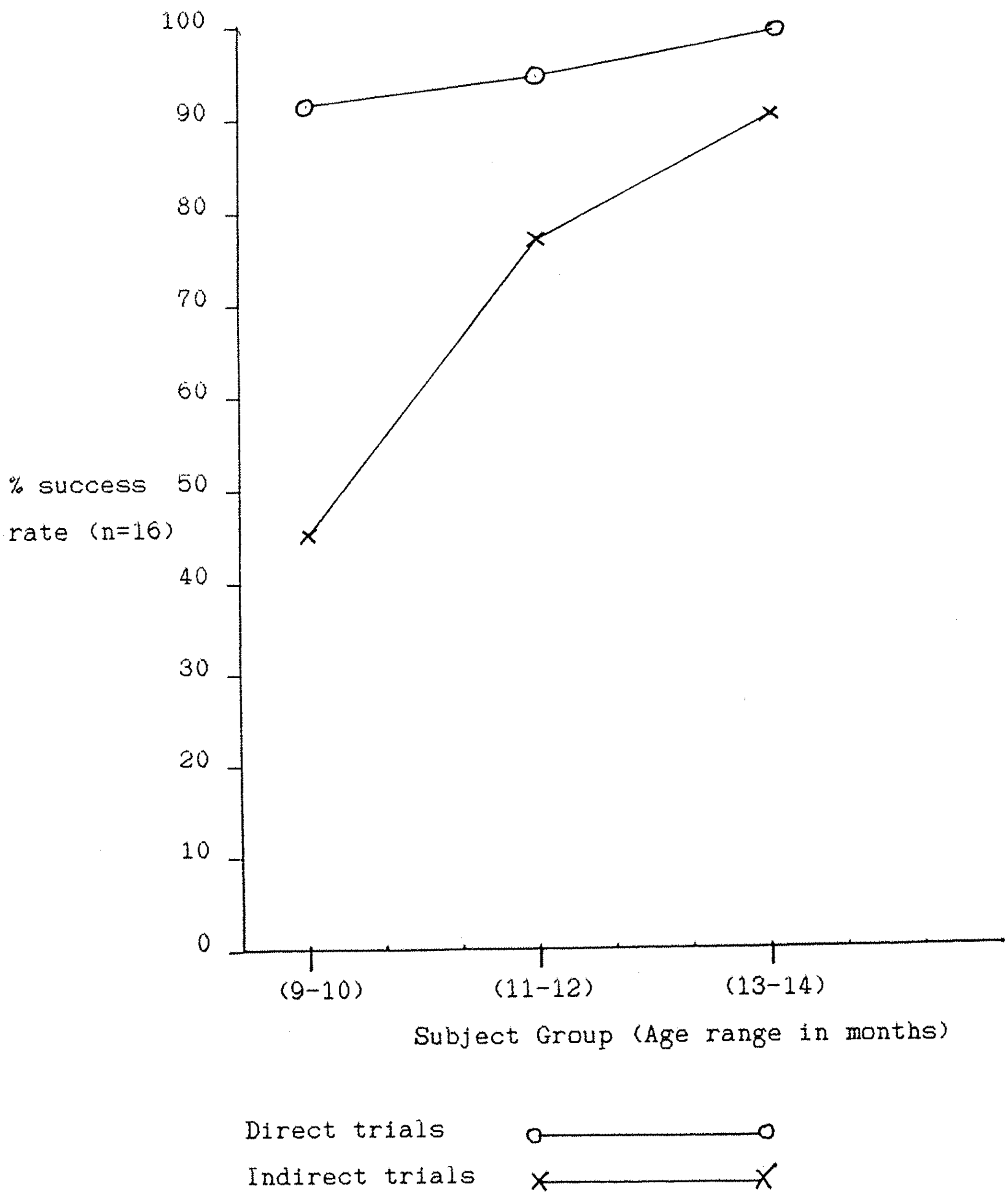
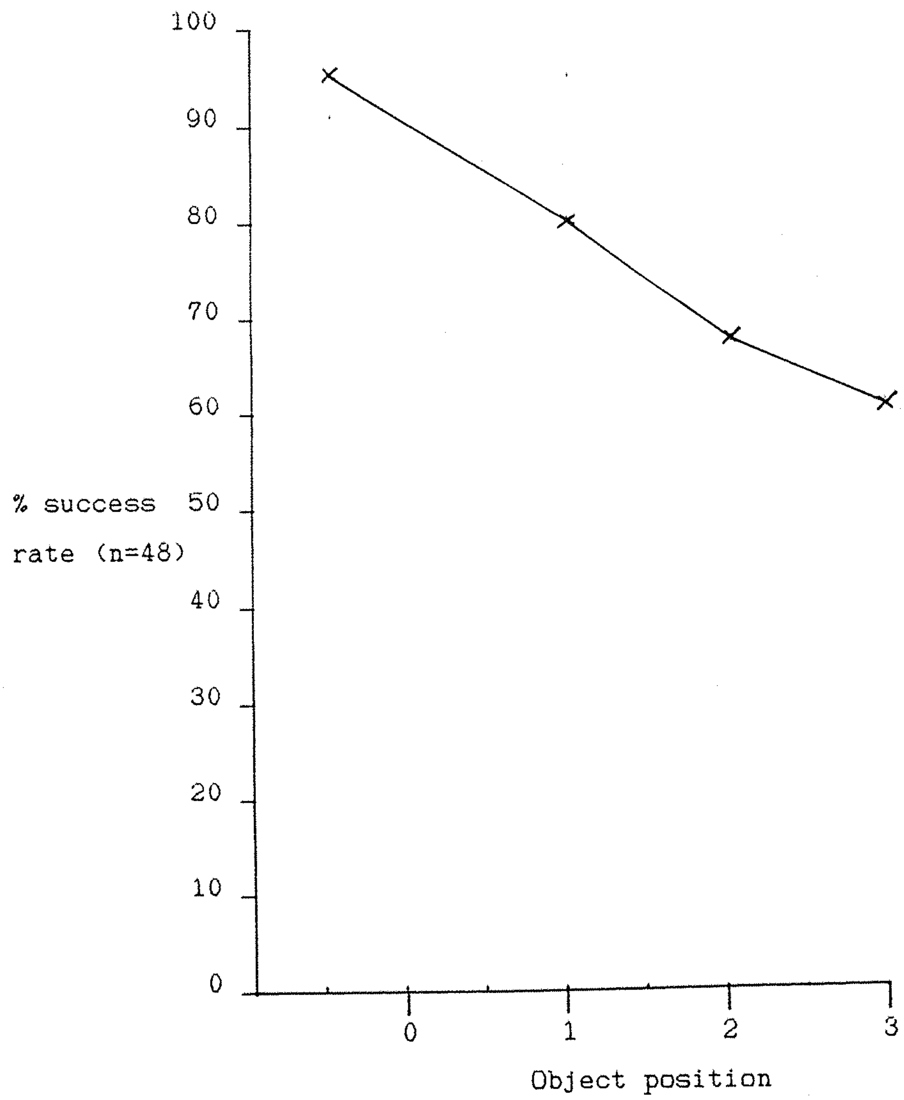


Figure 7.3. Experiment 5.

Graph Showing Mean Success Rate for Different Object Positions



0 open position (Direct)

1 edge position (Indirect)

2 1.2m in from the edge (Indirect)

3 2.4m in from the edge (Indirect)

Comparison between manual and locomotor detour problem solving.

The results of experiment 4 and 5 were compared to evaluate the hypothesis that manual detour problems are solved developmentally earlier than locomotor problems. In order to make this comparison, only subjects who completed both experiment 4 and 5 were included in the analysis. The infants in the reaching study performed 8 Indirect trials while the same infants only performed 6 Indirect trials. In making this analysis it was decided to use a criteria for success as Lockman had in his experiment of 2 successful responses. It was reasoned that if an infant could repeat a detour solution at least once then this indicated that whatever the method of solution, the infant was unlikely to be succeeding by accident. Lockman's criteria was more rigorous in that he used a criterion of 2 successes out of 3. However the design of experiments 4 and 5 was determined primarily to investigate other factors and this meant different numbers of trials between experiments. The longer time taken to perform a locomotor detour meant that equal numbers of trials in experiments 4 and 5 would make the locomotor experiment substantially lengthier than the reaching experiment.

This comparison was made using the McNemar χ^2 test comparing:

a) The number of subjects who reached the criterion on the Indirect reaching task but not on the locomotor task with-

d) The number of subjects who reached the criterion on the Indirect locomotor task but not the reaching task.

The results of this analysis showed that overall there was no significant difference between the locomotor and reaching tasks (a=5, d=3, p=.36 n.s. binomial test used beacause of low frequencies). Hence there was no evidence for a developmental lag between locomotor and reaching detour problems in the investigated age ranges. It must be concluded that the cross sectional method would probably require a larger sample to obtain a significant result.

7.4. Discussion

The results of experiment 5 are contrary to those of Lockman (1984). As well as an expected significant developmental trend, the change in position of the mother disrupted the performance on the task (see Figure 7.3.). The reasons for this are probably due to the larger scale of the task. However it seems unlikely that the reason for this was due to the requirement for a larger space to be represented mentally by the infant. If this were so then we would expect the longer screen position to disrupt performance which it did not. Further the interaction between screen length and object position was not significant. This is the variance due to the absolute length of the detour path.

The probable reason why this effect was observed concerns the infants tendency to go initially towards the mother. Infants looking at the mother (object) are turning away from the edge of the screen. At the deepest position (3) the angle subtended at the infant approaches 90°. The infant can still perceive both the object and the edge of the screen in the periphery of vision. However if the infant moves towards the object and away from the edge of the screen this angle rapidly increases up to 180° or at least to a point where both object and screen edge cannot both be perceived clearly. Under these circumstances (as observed by Lewin 1936) the detour task becomes more difficult. Thus once a direct approach to the screen is made, the chances of correcting the error are small. If the infant begins by moving towards the object then the initial position of the infant rapidly becomes unimportant in the geometric equation. It is the position of the object which determines where the terminal position of the infant pursuing a direct path ends up not her own initial position. Compare this with the reaching situation where a direct reach can be corrected very rapidly from the stationary position of the observer.

The level of performance was higher than expected for the 9-10 and 11-12 month age groups (46% and 75% respectively). The infants in these age groups would normally be expected to fail such a test on Piaget's theory. However as pointed out above, the displacement required here is similar to that of a displacement of self action described in experiment 4. The conclusion is either that these infants are displaying true associative groups of displacements or that the task itself does not tap such displacements. The displacement of the subject to the edge of the screen is on the analysis above not a true associative group but a reversible displacement. The task of the infant is to inhibit the direct response and avoid losing sight of the edge of the screen. The perception of the screen edge as a sign of potentially removing the barrier to action does not of itself indicate associative groups are understood. As such signs are perceived during stage IV it is concluded that the locomotor detour task may be solved in stage IV ie. before around 12 months. However the detour reaching task without the displacement of self action does indicate the availability of associative groups and as such is a stage V task in Piaget's terms.

7.5. Summary

1. In the experiment reported here, three groups of infants were tested on Direct and Indirect locomotor problems. The age groups studied were 9-10 months, 11-12 months and 13-14 months, 16 in each group. Out of the subjects seen only 3 infants could not locomote independently.

2. The study had two aims. First to investigate the effects of spatial variables on performance in a locomotor detour problem. A previous study had shown that varying the position of the object and the length of the screen had no effect on infant peformance (Lockman 1984). However in that study the detour space was relatively small and the experiment reported here aimed to investigate these variables in a larger scale space. The second aim was to investigate the relationship between manual and locomotor detour problem solving. In another longitudinal experiment Lockman showed that the reaching problem was solved at an earlier age to the locomotor problem. The effect of comparing infant performance in a larger locomotor space with a manual detour space was thus seen as a valuable comparison with Lockman's data.

3. The results for the locomotor detour problem showed that the length of the screen relative to the infant had no effect on peformance. The position of the mother who held the goal object was highly significant. It was suggested that this spatial variable was disruptive of problem solving in the larger space. When infants characteristically moved initially towards the mother the edge of the screen went out of sight. The infant would be unable to solve such a problem without an internal representation of space. This problem of correcting an initial direct attempt was less of a problem with the object near the edge of the screen.

4. A comparison between experiment 4 and 5 showed there was no significant difference between performance on locomotor or reaching detours. However it was possible that such an effect

might be shown up with a larger sample or in a further longitudinal study.

CHAPTER EIGHT

DISCUSSION AND CONCLUSIONS

8.1. Introduction

This thesis concerns the earliest kinds of indirect problems which infants are able to solve. The ability to go around a simple detour barrier provides both a link to earlier and later development. The ability to walk around an environment filled with obstacles and hazards is one that is taken for granted. However such abilities develop out of earlier skills which have their origins in early infancy. Other simple problems like removing a cover from a hidden object appear developmentally before detour solutions (Lockman 1984). The relationship between these simple early abilities is far from straightforward though. It might be thought that removing a cover from a hidden object indicates the understanding of the relationship 'behind'. If the infant can understand behind in this context then presumably she can extend this understanding to go around behind a simple transparent screen. Such is not the case. Removing a cover from a hidden object does not necessarily imply the relationship between cover and object is fully understood, as Piaget (1954) pointed out. Nor does this ability generalise to different ways of going behind an obstruction.

In this thesis only transparent detour tasks were investigated. This was because the task analysis in the opaque barrier problem is in many ways very different. It must not be indicated though that in the real world life is so clear cut. In many cases different perspectives provide real detour problems where objects partly occlude paths and goals and a multiplicity of detour routes is potentially available. These kinds of different problems relate to perception, cognition and motor skills. In this regard such detour problems have a potential for unravelling many theoretical questions in developmental Psychology.

8.2. The Origins of Detour Problem Solving

In chapter 1 three theories which seek to explain the origins of detour problem solving were outlined. The key ideas of Kohler (1927) revolve around the concept of 'insight'

Kohler (1927) carried out research on learning detours and other indirect problems with apes and monkeys as subjects. He also made some observations on human infant subjects performing detours. Kohler proposed that many of the solutions to detour problems could not be explained by trial and error learning or shaping procedures. Many of his monkey subjects hit upon solutions to problems suddenly and with no previous experience of the task at hand. The solutions were readily repeated on future trials. These kinds of solutions he called insightful. Other researchers in the animal tradition have questioned whether innate constituents of these insightful responses were not responsible for the sudden appearance of new solutions (Schiller 1952). Further the role of previous experience has been examined in relation to new solutions to indirect problems (Birch 1945).

There are two possible interpretations of the term insight. One concerns a description of a particular form of problem solving. This implies a second interpretation, that of insight as a process. In as much as Kohler intended this interpretation he described the process in terms of tension in the perceptual field. This tension gives rise to instability and under certain circumstances this leads to a sudden re-structuring of the perceptual field in which the subject 'sees' the solution. This formulation is similar to that of Lewin (1935). The trouble with this conception of insightful learning is that it is not at all clear precisely how this re-structuring occurs. As a description of a particular kind of problem solving insight has some face validity. As a process it is hard to see how it has any explanatory value.

In a very elaborate and sophisicated theory Piaget (1954) sought to explain how infants come to perceive and understand the world into which they are born. For Piaget, the insight that Kohler described in his subjects has a long developmental history. The growth of sensorimotor intelligence in the infant is crowned by the development of the object concept. The object concept is achieved when the infant understands the spatio-temporal identity of objects in space and time. Once the concept of a permanent object is established in the mind of the infant she is able to form mental representations of objects and their relationships with each other and herself as an object. These mental representations are not fully developed until the end of the second year of life. The mental representations enable the infant to perform just such insights as Kohler described. The infant is no longer tied into a world of action.

The importance of Piaget's theory for the study of detour problems is his theory of the development of space. The infant through her actions on the environment constructs first a practical then a subjective and finally an objective space. In so doing she constructs what Piaget terms groups of displacements. Two of these groups are of importance here.

The reversible group is exemplified where an infant performs an inverse action. The typical example is the removal of a cover from a hidden object. This action is the inverse of the original hiding. Such reversible displacements are characteristic of stage IV (roughly 8-12 months). The associative group is exemplified by the detour solution. An associative group might be combining the displacements AB and BC to form the displacement AC. Such groups would permit the infant to go from A around the edge of a barrier B (AB) and then from B to C behind the barrier (BC). The direct displacement AC is not accessible in the detour problem and hence the requirement for associative groups. These associative groups first appear in stage V of sensorimotor development (roughly 12-18 months) for visible detours. According to Piaget detours where part of the route is not visible require the invisible space to be mentally represented. Hence associative groups for detour problems with opaque barriers should not appear until mental representation in stage VI (roughly 18-24 months).

The evidence does not support this sequence. Lockman (1984) found that infants succeeded on an opaque barrier detour test before reaching stage VI of development. Further the opaque barrier task was solved a month earlier on average than the transparent barrier task. In a cross-sectional study of detour reaching, Bruner (1970) recorded similar results. Young infants were better at detour tasks where they couldn't see the object. From these results it would appear that either associative groups of displacements appear earlier than Piaget indicated or that the infants in the two studies cited were solving the detour problem without associative groups.

Bruner gave two clues as to the answer. First he observed that for opaque conditions the infants would lean around the edge of the barrier to reinstate the sight of the object before reaching for it. Secondly he observed that for transparent conditions young infants usually reached out directly to the locus of the object at the start of the trial. The majority of 6-9 month old infants never got beyond this level (although in some conditions 30% did succeed). He observed a strong developmental trend in the ability to inhibit direct reaching. This indicated that neuro-psychological factors might be important. The leaning round the screen indicated that the associative groups of displacement may not be the mechanism whereby infants succeed prior to one year of age.

It is argued in this thesis that the leaning (or displacement of self) action is not an associative displacement. The terminal reach following this action from the edge of the barrier to the object behind is a direct one. There is nothing in the initial action which indicates that the following reach is planned or anticipated. The displacement around the screen is on this view a reversible displacement and develops during the stage IV period.

It was proposed that such a displacement of self may be available in transparent detour problems in stage IV. This might explain why some infants solve this problem prior to an age comensurate with stage V. The possibility of a displacement of self reversible operation leading to true associative groups of displacements is an empirical issue

Bruner's detour study was done in the context of his theory of skilled action. On this view, with practice skills become sub-routines or modules. Such modules may be incorporated into into larger programmes and complex action sequences programmed. Bruner (1970) emphasised the serial ordering of such routines and the generativity of the programmes by analogy with language. The detour reaching task on this view involves the serial ordering of a sequence of sub-routines to achieve a goal. The creation of such a sequence implies the ability to dissociate the line of action from the line of sight. This involves inhibiting direct reaching and a representation of the detour path to feedforward possible solutions.

The neuro-psychological evidence cited in chapter 2 has implications for the manual solution of detour problems. The distinction between the distal and proximal systems in eye hand co-ordination have a neural and developmental aspect related to detour problems. The proximal system of the shoulder arm and hand is mediated by the extra-pyramidal tract and controls relatively gross movements. The distal system involves the fine adjustments of the hand and fingers and is mediated by the pyramidal tract. Following ablations to the pre-motor cortex of a rhesus monkey, Moll and Kuypers (1977) discovered that their subjects were unable to guide the hand contra-lateral to the ablation in a detour movement. They hypothesised that an inhibitory mechanism was disconnected in this operation. This left the monkey unable to inhibit a direct reach. This similar behaviour to young human infants indicates that such a mechanism may only start to operate late in the first year of life.

It has also been demonstrated that the extra-pyramidal tract develops earlier than the pyramidal tract in monkeys (Kuypers 1962; Lawrence and Hopkins 1977). This asymetry reflects the pattern of reaching skill in human infants. It is possible that the detour reach is a higher order skill which has a similar neuro-ontogenetic lag. The cortical control of the eye-hand system is necessary to incorporate more spatially complex programmes. Hence the development of the ability to perform a detour reach early in infancy may reflect a final stage in neural development where the distal reaching system is taken over by a cortical process of represented space.

8.3. Summary of Principal Findings

The research reported in this thesis is contained within five experiments. These all concern detour problems in which the whole situation is visible. The barriers and screens used in the studies are thus transparent. The detours required are to go around the obstacle in order to retrieve an object. In each case aspects of how infants come to solve such simple problems are investigated in different age groups and under different spatial conditions.

In the first study it was shown that infants of 8-10 months totally fail to retrieve an object from behind a screen by reaching in a detour action. These same infants were all able to remove a cover and retrieve a hidden object. This indicates that the problems are structurally different. An older group (16-18 months old) are able to solve the problem quickly and often at the first attempt. The younger infants typically reach out directly to where the object is visible without any regard to the spatial circumstances of the task. It was noted that a displacement of self strategy was not used by infants and hence infants who succeeded were using a true detour reach. This showed the younger infants were incapable of the associative group of displacements in a visible space at least before 10 months.

The experiment also tested for search errors in a visible detour space. Surprisingly many of the older infants who could perform a detour reach made such errors. When the object was moved from the left to the right in the detour condition the 16-18 month group of subjects showed the divided pattern of search characteristic of 8-10 month infants. Instead of accessing the correct detour path half the infants continued to try to reach the object on the original side. By contrast the 8-10 month group attempted to reach on the correct side. Their reaches were though direct and unsuccessful.

The presence of errors in the older group may have been due to a failure to update a code for the new detour space. It was suggested that this may conflict with an allocentric code specifying left or right position relative to the background. Such an apparent return to earlier behaviour may represent what Bower (1974b) termed a repetitive process. Alternatively it was suggested that the errors simply reflected a failure to update the location code because of a lack of information processing capacity. Solving the detour problem may take up all the available processing capacity. The results though require further verification with a non-correction procedure.

In experiment 2 a further group of infants 12-14 months old were tested using the same apparatus and procedure as experiment 1. This was done to ascertain at what age infants began to solve visible detours. The results showed that there was a significant transition to success between 12 and 14 months of age. Other studies have demonstrated success on younger groups. Lockman (1984) found that infants solved a similar problem at a mean age of 10.7 months in a longitudinal study, Bruner (1970) found that 6-9 month old infants succeeded on 30% of trials. The difference between the results may have reflected the lack of the displacement of self action in experiments 1 and 2. Such actions may have occurred because of the design of the apparatus in other experiments. There were though other possibilities for the discrepancy. These were tested for in experiment 3.

The change in location from left to right during trials in experiments 1 and 2 may have affected performance. A 3 second delay before infants were allowed to reach out was imposed. Another possible source of the discrepancy was the short trial time which was 15 seconds. In experiment 3, 8 and 10 month old infants were tested under more optimum conditions on the same apparatus. In addition to a longer trial time and stable spatial conditions, the infants were given a training session by their mother. None of these changes significantly improved performance. It was concluded that the apparatus used which discouraged a displacement of self action was the source of the discrepancy. The experiments 1,2 and 3 were testing associative displacements and these were not available until around 13-14 months.

In experiment 4, a new apparatus was used which encouraged the leaning action. In addition spatial manipulations tested the hypothesis due to Bruner (1970) that behavioural space increases with age. The results showed that around half the infants would use a leaning action and then succeed by reaching in directly to the object. Such a sequence was more probable with the edge of the detour screen placed at the infants midline. This may have been partly responsible for the significantly better performance with the screen at the midline. The evidence for displacement of self actions leading to true associative displacements was not conclusive. The developmental trend was significant but the 9-10 month group showed a 34% success rate overall. This was far in excess of similar aged children in experiments 1 and 2.

The same subjects were tested on a locomotor detour test. Similar spatial manipulations were made. The results showed a significant developmental trend but the 9-10 month group still succeeded on 45% of trials. It was suggested that the structure of the locomotor detour problem inherently involved a displacement of self. The infant who succeeded in locomoting to the edge of the screen has only a direct movement to the object left to peform. It was suggested that this task in itself may not require the associative groups of displacements. The position of the object in this experiment was highly significant. It was suggested that this was because infants who moved directly to the object would under some conditions lose sight of the screen edge. Thus a correction of an initial direct movement was more difficult the further the subject moved from the screen. It was also possible that the larger space may require more mental representation. This hypothesis was rejected as the length of the barrier did not affect performance.

Comparison between reaching and locomotor detours showed no developmental lag as found by Lockman (1984). It was suggested that in a cross-sectional study a larger sample would be required to prove or disprove any trend.

8.4. Suggestions for further research

The research done to date on detour problem solving is very limited. We know very little about the relationship between developmental level and the ability to solve detours in either reaching or locomotor space. Lockman is the only researcher to date to investigate developmental variables in a longitudinal experiment. It would be useful to discover whether infants can solve detour problems with associative groups of displacments prior to the developments of stage V of sensorimotor development. This could be done with the appropriate Piagetian tests.

In experiment 3, the infants were given a five minute training session by their mothers. This was unsuccesful but additional training over a longer period might be successful in either manual or locmotor spaces. This would help to sort out the nature of the underlying neural substrate to such behaviours. If a cortical control mechanism were necessary then the training on the task might be unsuccessful. Such training tasks might provide valuable evidence on the degree to which neuro-physiological maturity controls spatial abilities in infants. It is entirely possible that associative groups and others are simply a function of maturation. Training groups at different age levels could be compared with a play control group. Manipulating the apparatus may provide another source of experience which enhanced performance.

Rader, Bausano and Richards (1980) investigated the responses of infants on the visual cliff when given the early opportunity of independent locomotion with a baby walker. It would be of interest to see the response of similarly trained infants in a locomotor detour problem. This again would provide valuable information on the role of experience in development.

There was no evidence that infants could be trained on the manual detour problem where the displacement of self action was not available. The evidence that the reversible displacement to the screen edge may generate associative groups received only equivocal support. However it would be possible to give special training in reversible displacements and discover whether these are linked to associative groups developmentally. The spatial configurations so far investigated in detour problems are very limited. It would be of significance to compare reaching around a vertical screen with reaching over and under a screen. There may be an asynchrony for these different spatial relations just as there is for terms relationships like in and on.

8.5. Conclusion

From these studies certain conclusions can be drawn. The development of detour problem solving has a developmental trend. Success on manual detour problems with transparent screens has shown that there are at least two ways to solve the problem. One is the planned detour reach which requires associative groups of displacements. The other solution is to displace the self around the edge of the screen and then reach in. This latter action may not be planned in terms of outcomes and indicates a reversible displacement characteristic of stage IV in sensorimotor development. In the case of the locomotor detour problems the movement to the edge of the screen is inherently a displacement of self. It was suggested that this may also be a reversible displacement. This might explain why there was a high success rate on the task prior to one year of age.

The experiments reported in this thesis do not appear to contradict Piagetian theory. However the perceptual competence of infants in numerous ways has given cause for re-examining the whole idea of how and if we learn to see and hence the relationship between perception and action. In this respect the detour problem provides a valuable tool for investigation here in future work.

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