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The relation between crawling and allocentric spatial coding in infants

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The Relation Between Crawling and Allocentric Spatial Coding in Infants

by

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Summary

Allocentric coding is a spatial orientation strategy whereby the location of a hidden goal is coded in relation to landmarks. Research showing that the ability to use this coding strategy emerges at around 9 months has led to the proposal that its development is linked to the onset of crawling; this proposal is referred to as the *crawling hypothesis*.

Spatial orientation abilities were measured by task performance in a circular enclosure whereby, during training trials, infants were presented with an event (the appearance of an adult playing "peek-a-boo") from various viewing positions. During subsequent test trials from a new viewing position, no event was presented, and infants' looking responses were recorded. The experimental condition environment contained visual features landmarking the event's location; the control condition, by contrast, contained no visual features.

A series of cross-sectional studies examined whether infants younger than 9 months were able to use allocentric coding after a simpler reorientation (Study 1) and with a facilitating training regime and more salient landmarking (Study 2). A further study (Study 3) replicated the methodology used by Tyler and McKenzie (1990), who reported high levels of performance in 6- and 8-month-olds. Overall the findings from these studies left open the possibility of the crawling hypothesis as a viable proposal.

A longitudinal study (Study 4) examined the link between the onset of crawling and allocentric coding—by monitoring the development of spatial and motor abilities from 5 to 11 months—and provided little evidence to support the crawling hypothesis.

Consequently, alternatives to the crawling hypothesis are considered (such as visual attention and exploration linked to brain maturation).

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Dedications

It is ironic that during the time it has taken to complete this thesis on spatial cognition and orientation, feeling lost and disorientated has been so prevalent. Although being lost is relative, *feeling* lost is far from relative. It has also become apparent that doing a PhD is equivalent to mapping an unexplored terrain; feeling lost and disorientated go hand in hand with completing such a task.

Fortunately, this thesis has concentrated on the use of landmarks and their value in helping us to stay orientated. Landmarks provide guidance and a sense of direction and assurance.

In life, the loss of significant landmarks makes navigating your way very difficult. This thesis is dedicated to all those landmarks in my life who helped me navigate my way along this journey.

Abide with me.

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THE DEVELOPMENT OF SPATIAL CODING STRATEGIES IN INFANTS

When attempting to locate an object hidden in an otherwise featureless environment, it is vital to stay orientated. Staying orientated in such an environment requires keeping track of one's movements. Coding locations relative to oneself, and then updating this coding to take account of that movement, is an example of the spatial coding strategy known as *egocentric* coding. This is a useful strategy when the environment is otherwise featureless. However, when visual features are present in the environment, the location of the hidden object can be coded relative to these visual features; therefore coding location in such circumstances does not require keeping track of one's own movement. Coding locations relative to visual features in the environment is an example of the spatial coding strategy known as *allocentric* coding.

This thesis focuses on examining the development of allocentric spatial coding. It aims to establish the age at which infants begin to be able to use such a strategy and to uncover possible causal factors linked to the emergence of this ability.

The following review is divided into four sections. The first presents research on the development of infants' spatial understanding from an historical perspective, demonstrating how ideas about their understanding of space have evolved. The second concentrates on research examining infants' abilities to stay oriented in large-scale space; this section introduces the main research paradigm used and suggests important methodological considerations that need to be taken into account when examining infants' abilities; it ends by presenting a timeline for the emergence of spatial coding strategies as deemed by current research. The third part begins Chapter 2 and focuses on the main causal factor suggested to bring about the emergence of allocentric coding: the development of crawling. The fourth presents alternative suggestions to the hypothesis that crawling is a major causal factor in spatial development .

The Spatial Abilities of Infants—An Historical Perspective

Piaget's View on Infants' Spatial Understanding

From his observations of infant behaviour, Piaget (1954) believed that knowledge of the world develops from sensory inputs. He therefore viewed infants' understanding of the world as being dependent upon their sensorimotor development. Because infants' knowledge and understanding is based on their experiences, infants first form a subjective view of the world. Piaget uses the term *egocentric* to describe this subjective view of the world. Because he believed infants to have an egocentric understanding of the world, he also labelled their behaviour as egocentric. This use of the term egocentric is different from that used in spatial literature: Such literature uses the term to denote coding locations with respect to one's movement, orientation, and position. Piaget uses the term to describe the belief infants have that occurrences are contingent on their own actions; that is, that the world is not separate from themselves. Therefore, when Piaget applies the term egocentric to spatial issues, it is to portray infants as having their own concept of space; this version is non-distinct in which oneself is not viewed as a separate object within space. As infants' sensorimotor abilities develop, Piaget emphasises that they gradually move away from having an egocentric view of the world, and move towards having a view of the world that is non-egocentric (an objective view, whereby oneself is viewed as a separate object within space).

Before infants obtain a fully objective view of the world, Piaget explains that their understanding of the world is poor. This poor understanding is reflected in their behaviour. An illustration of such poor understanding was noted when Piaget observed that it is not until around 8 months that infants begin to search for a hidden object. Infants are able to reach for and retrieve an object from about 4 to 5 months. Hence this failure to search for a hidden object cannot be explained by an inability to carry out the necessary action. Piaget explains infants' failure to search for a hidden object as demonstrating that they did not yet understand the object to exist when it was out of sight; this is a level of understanding Piaget refers to as signifying a lack of understanding for *object permanence.*

Piaget noticed that infants' ability to retrieve hidden objects is still limited at 8 months. He discovered that, if the object is moved and hidden at a different location, then infants search for it back at the place where it was found previously. Piaget explains this search error by stating that infants consider the reappearance of the hidden object to be contingent on their action of searching (i.e., reaching to the previous locaton). Hence infants believe the object to reappear whenever they carry out the previous action again. This false belief therefore results in infants making the search error whenever the object is moved and hidden at a new location.

The AB search task.

The task, in which the infant is required to search for an object after it has been moved, is known as the *AB search task.* In the standard AB search task the infant is seated in front of two identical locations (one to the left and the other to the right). A toy is hidden under a cloth at one of the locations (referred to as 'A'), and an identical cloth is placed at the other location (referred to as 'B'). Once the toy is hidden at A, the infant is allowed to reach and retrieve it. After several trials of the infant successfully retrieving the toy at location A, the experimenter hides the toy at location B. This transition of the hiding place is carried out in full view of the infant. The infant's failure to retrieve the toy from location B, by searching back at location A, is known as the *AnotB error.*

Alternatives Explanations for Search Errors

Since Piaget first observed infants making this type of search error, some research findings suggest alternative explanations for its cause. Some research shows that infants may possess an understanding of object permanence at 3.5 months (Baillargeon, 1987a) and 2.5 months (Spelke, Breinlinger, Macomber, & Jacobson, 1992).[1] Such findings suggest that the failure to search correctly is due to factors other than lacking an understanding of object permanence. Many studies have since been carried out to determine why the AnotB error occurs. Variations of the AB search task reveal that the search error occurs under some conditions of the task, but not under other conditions. These variants of the task are reviewed in parts of the following section.

Suggestions explaining why infants make the AnotB error highlight numerous possible causal factors. One factor is insufficient memory. Studies show that if no time delay exists between hiding the object at location B and allowing the infant to search, then infants search correctly at location B—that is, infants make no AnotB search error (Diamond, 1985). The presence of this delay in the standard task may place too great a demand on the infant's memory capacity. Extensive work by Diamond on the effect of this delay shows that with age infants become increasingly capable of withstanding longer lengths of delay between the hiding of the object and retreiving it. These findings indicate that memory is a component required to succeed on the AB search task, that is, if little memory is needed then task performance improves.

However, the lack of sufficient memory capabilities cannot be the sole cause of this search error. Other research shows that infants continue to make the AnotB error even when the toy remains visible at location B. Such studies have used either a transparent cloth to cover the toy (Butterworth, 1977; Harris, 1974) or have simply left the toy uncovered (Bremner & Knowles, 1984). If insufficient memory is the sole cause of the search error, then it seems unusual that infants continue to make the search error when the object remains visible; such task conditions require no memory as to the object's location.

Some theories, relating to memory, suggest that the cause of the search error is linked to competition between the memory of the toy at location A and the most recent (and possibly less strong) memory of it at location B (Harris, 1989), problems in

[1] Dispute exists about these findings and their interpretation; for a review, see *Infancy* (2000) 1 (vol. 2).

distinguishing between the two locations (Cummings & Bjork, 1984), and deficits in attention to target location during delay (Acredolo & Horobin, 1986)

Since some studies show that infants continue to make the search error even when the toy is visible, other studies have set out to examine the possibility that the AnotB search error is the result of problems in directing the correct manual search (i.e., carrying out the correct reaching response). It has been discovered that in many situations infants at this age are not yet able to inhibit a previously rewarded response (Diamond, 1988). With regard to the AB search task, reaching to location A is a previously rewarded response; the reward being the retrieval of the toy. This discovery—that young infants are unable to inhibit certain motor responses—therefore explains infants' failure to search at location B as being due to their inability to inhibit the motor response used to find the toy when it was at location A. This explanation implies that infants know the toy to be at location B, but that they are unable to search at this location because they are unable to inhibit the reaching action to location A. Diamond states that the dorsolateral prefrontal cortex region of the brain plays an essential role in inhibiting prepotent actions. It is only when this region of the brain has matured sufficiently that infants are able to inhibit reaching at location A, and to begin reaching at location B, in particular when working memory is taxed, that is, when the object is hidden and a delay is introduced prior to search. This neurological account of the AnotB error is supported by other work examining the function of the frontal cortex on AB search task performance (Bell & Fox, 1992).

However, although some studies implicate infants' failure to inhibit a prepotent motor response as the factor causing this search error, other studies show infants continuing to make the AnotB error even when the task requires no previous motor response (Butterworth, 1974). Other researchers claim that, by removing the requirement of making a response, infants show knowledge of the object at location B (Ashmed & Ruffman, 2000).

In summary, despite many attempts to explain why infants make the AnotB error, none as yet are able to explain it fully.

What Does the AnotB Error Tell Us About Infants' Spatial Coding Abilities?

Despite the AB search task's original illustration of infants' spatial understanding, few spatial explanations of the search error have been proposed. Some research aimed to establish how infants code the object's location when it is at location A. This research suggests that the AnotB search error occurs because infants are unable to update their coding of the object when the object is moved to the new location (location B). Bremner (1994) suggests that the AB search task might be better interpreted as a spatial problem.

By adapting the standard AB search task, it is possible to determine whether infants code the toy's location at A as either relative-to-themselves or relative to an external frame of reference. Making the distinction between the two types of coding is not possible with the standard task; both types of coding result in the same behavioural response. Butterworth (1975) and Harris (1973) found that at this age (i.e., around 8 months) infants use the relative-to-themselves coding strategy to code the location of the toy when it is at location A.

The use of this coding strategy—in which the object's location is coded relative-to-oneself—needs updating after movement of either the object or oneself. The reason this coding needs updating is because executing the relative-to-self response (i.e., the previous response) is only valid when the position of the object relative to the person remains unchanged. However, in the AB search task, the position of the object relative to the infant does not remain unchanged. The object is first hidden at location A, then it is moved and hidden at location B. When infants use the relative-to-self coding strategy to code the object's location at A, it is necessary for them to update this code to take account of the object's movement to location B in order for them to succeed at the task (i.e., to retrieve the toy when it is hidden at location B). Therefore, the AnotB search error can be seen as demonstrating infants' insufficient spatial abilities; that is, their failure to search at location B can be seen as due to their inabilty to update the coding used to find the object when it was hidden at location A.

Bremner and Bryant (1977) confirm that, when the object is hidden at A, 9-month-old infants are using a relative-to-self coding strategy. In their study, after hiding the toy at location A, infants were moved to the opposite side of the table or the table was rotated 180^0. As in the standard AB search task, a toy was then hidden at one of the two locations. In some conditions of this version of the task, the toy was hidden in the same location (i.e., location A). Following movement of either the infant or the table, infants were required to make a new response because the toy's location was in a new position relative to themselves (although it remained hidden at the same location). Thus the demands of correct performance required infants to update their reaching response. If infants failed to reach to the correct location— that is, by searching at the other location (but at the same position relative to themselves)—it can be inferred that the infants were using the relative-to-self coding strategy to code the toy's location before being moved. This was what Bremner and Bryant found.

The heavy reliance on a relative-to-self coding strategy may therefore be causing the AnotB search error; it is evident that infants are unable to update this type of coding strategy following movement of the object and of themselves. This was further confirmed by additional conditions carried out by Bremner and Bryant (1977). In these conditions the toy was hidden at location B. This latter set of conditions requires infants to reach to the same location relative-to-self. In these situations it is difficult to determine correct from incorrect performance as a correct reach could be the result of a response repetition.

Bremner (1978a, 1978b) found that by making the cloths used to hide the object distinct colours—thus visually differentiating the two locations—infants were less likely to make the search error. In Bremner's (1978b) study, movement of the infant or the table occurred after the toy was hidden. The spatial demands of this task were such that after movement of the infant, infants were required to update their reaching response to take account of their own movement; after movement of the table, infants were required to visually track the movement of the location of the hidden object. These strong visual features may help infants to rely less on a relative-to-self coding strategy.

This reduction in the search error when strong visual cues are present demonstrates that, when such cues are salient enough, infants are able to code the object's location relative to visual features in the environment.

Accurately locating a hidden object after self movement can be achieved if one is able to stay orientated. To stay orientated it is necessary to adopt the appropriate coding strategy. Infants are poor at staying orientated. This difficulty in infants' ability to stay orientated is caused by a heavy reliance on the relative-to-self coding strategy as it needs updating after movement (Bremner & Bryant, 1977). It is the updating of this strategy that infants are unable to do at this age, as evident from the existence of the AnotB search error. However, infants are able to locate the goal when visual cues are direct and salient enough (Bremner, 1978a, 1978b). The use of this type of external coding strategy (possible when the targeted location is marked directly) does not require updating after movement of either the object or oneself.

Infants' Spatial Orientation Abilities

Large-Scale Space

The previous section illustrated some of the spatial abilities of infants. However, the section dealt only with small-scale space; that is, reaching space.

Bremner's (1978a, 1978b) studies demonstrate that infants are able to relocate a hidden toy within reaching space after their own movement if that location is made visually distinct; this demonstrates infants' ability to locate the goal using visual features.

The ability to stay orientated also applies to large-scale space. However, a distinction exists in the cognition involved in representing small-scale space (reaching space) and large-scale space (that beyond reaching space) both at a functional and neurological level (e.g., for neurological support concerning this distinction see Brain, 1941; Haligan & Marshall 1991). Research examining infants' spatial orientation abilities mainly involves examining their understanding of space beyond reaching space.

The main focus of this thesis is on the ability to use visual features—present in the environment—to stay oriented; that is, the ability to use an allocentric spatial coding strategy. In such situations, these visual features are often referred to as *landmarks*.

Studies of Infants' Egocentric and Allocentric Spatial Coding Abilities in Large-scale Space

Studies examining the ability of infants to locate a hidden object (or event) using landmarks also examine their ability in the absence of landmarks. This is because examining infants' performance when landmarks are present is achieved by comparing such performance with their performance when no landmarks are present. Much of this research therefore investigates task performance when landmarks are present and when they are absent. The former situation, when landmarks are present, requires the spatial strategy known as allocentric coding; the latter, when landmarks are absent, requires the spatial strategy known as egocentric coding.

Such research therefore provides data on infants' task performance with respect to both egocentric and allocentric coding abilities. However, the presentation of the findings from this research has rarely separated these two abilities.

This section of the review is divided into three parts, one on egocentric coding, one on allocentric coding, and one integrating the two. Because of this, certain studies are dealt with more than once; first their findings with respect to egocentric coding, followed by their findings with respect allocentric coding.

The first part deals with research on infants' performance on spatial tasks where no landmarks are present—research examining infants' egocentric spatial coding abilities. In such task environments, infants successfully relocate a hidden object, after they themselves have been moved, by monitoring their own movements; such monitoring is necessary because, the experimental environment used is, by definition, visually impoverished (devoid of visual features).

The second part deals with research on infants' performance on spatial tasks where landmarks are present—research examining infants' allocentric coding abilities.

Here one suspects that infants find such tasks easier; this is because, in addition to using movement cues, they may also use visual ones. As we shall see, much of the research literature supports this suspicion.

The third section summarizes findings on infants' egocentric and allocentric coding abilities and proposes a developmental time line for the emergence of each ability.

Egocentric Spatial Coding

The "Peek-a-boo" Paradigm

Acredolo (1978) devised a paradigm that requires a looking response rather than a reaching response to examine infants' spatial abilities. The paradigm also examined infants' abilities to locate a hidden event rather than an object. The event was the appearance of an adult playing "peek-a-boo". This appearance always occurred at the same location. The study aimed to examine whether infants are able to successfully relocate the event after they are moved to a new position, that is, after their spatial relationship to the event is altered.

Acredolo (1978) used a square room which had two windows positioned on opposite walls. The infant sat in a chair in the middle of the room between the two windows. The chair was not positioned at the centre of the room; instead, it was set back slightly nearer one of the end walls. The two windows were therefore situated slightly in front of the infant, with one to his or her right and the other to his or her left.

From this position in the room, the infant was trained to anticipate the appearance of an adult at one of the windows. During each training trial, a buzzer sounded and was followed, three seconds later, by the appearance of an adult at the event window playing "peek-a-boo". Training continued until the infant turned towards the event window after the buzzer but before the adult appeared. After training, the infant was moved to the opposite side of the room. From this new position, the event window that was to the infant's left during training was now to its right, or vice-versa. Following movement to this new position, five test trials began. During each test trial, the adult did not appear after the buzzer. The infant's response was recorded and used as an indicaton of which window he or she expected the adult to appear.

Would the infant be able to successfully relocate the event window? If the infant could, then such a response would require him or her to look in the opposite direction to that which he or she looked during training. This successful relocating of the event indicates that the infant was able to take account of his or her movement and update the trained looking response accordingly. However, if the infant looked to the wrong window—that is, just continued to repeat the looking response that was accurate during training—then such would indicate that he or she was unable to update the trained looking response accordingly.

Acredolo (1978) examined the performances of 12 infants, each tested at three ages: 6, 11, and 16 months. Out of an average of the five test trials, only one or two of the 6- and 11-month-old infants looked towards the event window; the other infants repeated the response that was successful during training, and hence looked towards the wrong window. At 16 months, infants performed better: Eight infants successfully relocated the event window.

These results suggest that only 16-month-old infants are able to relocate the event window after movement, and that younger infants respond by repeating the previously learned looking response.

The fact that infants look to the event window during training—in anticipation of the event—demonstrates that, at all three ages, they are able to code the location of the event window relative-to-themselves. During training, the repetition of this looking response corresponding to this type of coding strategy for the event's location (i.e., the relative-to-self coding strategy) is a well suited strategy because it results in successfully relocating the event window. However, this response strategy becomes redundant when the infant is moved to the new position. To relocate the event window after movement, it is essential that this relative-to-self code is updated to take account of the movement. This updating requires the ability to keep track of one's own movement.

These findings by Acredolo (1978) therefore suggest that 16-month-old infants are able to take account of their movement, but that infants at the two younger ages are not yet able to do so.

However, the inaccurate responding of the younger infants—that is, the continued repetition of the trained response—may be due to the training procedure. During training, only one looking response is trained, that is, a head turn to either the right or the left. The continued repetition of just one head turn may heavily influence infants' responding on test trials. The younger infants may associate the event with their looking response rather than with a particular spatial location. This looking response association is possible because infants are required to reach a satisfactory level of anticipatory looking during training; that is, the event is presented once the infant has turned towards the event window. The occurrence of this association implies that a form of behavioural conditioning may develop such that the task becomes one requiring infants to produce a particular response, rather than to find the event.

Multi-Locational Training

A way to reduce this possible confound (i.e., accidentally conditioning a particular response during training) would be to train the infant from more than one position. This way, the infant is required to make a different response during training before he or she is moved to the test position. This second training position may help the infant to associate the hidden event with a *place* rather than with a *response*.

Keating, McKenzie, and Day (1986) used this method and trained infants to anticipate the appearance of an event (an adult playing "peek-a-boo") from two separate positions of facing. Infants were then tested from a third, new position. Infants were situated in the centre of a square enclosure and were rotated to face different directions. The "peek-a-boo" event occurred at a fixed location following a cue (a jiggling ball). Identical balls were used for this purpose; each ball was positioned at equal distances around the perimeter of the enclosure. From each training position, the ball directly ahead of the infant was jiggled to gain his or her attention. Once the infant fixated on the ball, the ball stopped jiggling, and the adult appeared playing "peek-a-boo". Training took place from two positions of rotation from facing the event site: 90^0 to the left or right and 45^0 to the right or left. Infants were therefore trained to produce responses that were 90^0 to their left or right and 45^0 to their right or left. Upon reaching accurate anticipatory looking from each training position, infants were rotated around the centre of the square enclosure to the test position 90^0 right or left from facing the event site. At this position two test trials occurred. On each test trial, the adult did not appear after the ball stopped jiggling. The question concerned where the infants would look to anticipate the appearance of the "peek-a-boo" event.

Keating et al.'s (1986) results showed that seven and six 8-month-old infants (out of 16 infants) looked towards the event site on test trials one and two, respectively[2]. These results suggest that training from more than just one position improved infants' performance. Some infants are able to relocate a hidden event in a visually impoverished (non-landmarked) environment.

Acredolo (1978) trained infants from only one position and was able to show this level of ability in 16-month-old infants only. This difference between the two studies suggests that infants (the younger ones especially) are sensitive to response conditioning. Therefore, to overcome the effect of this sensitivity, it seems necessary to train infants from more than one position.

However, it is possible that the type of movement used to move the infants may have contributed to the increased level of performance reported by Keating et al. (1986) compared to Acredolo (1978). Infants in Acredolo's study were moved to the test position using a movement which involved both rotation and translation, whereas Keating et al. used a movement which involved rotation only. A movement involving both rotation and translation is more complex than one involving rotation only. The simple movement of rotation only used by Keating et al. may be easier for infants to

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[2] McKenzie, Day, and Ihsen (1984) also used multilocational training and reported correct responding in 10 and 13 infants out of 15 for test trial one and two, respectively. However the environment used was less cue controlled (i.e., the outer room was visible) and the measure of correct performance was less strict, thus making comparisons difficult.

keep track of; therefore the use of this simpler movement may enable infants to update their trained response after moving to the test position more easily.

Meuwissen and McKenzie (1987) examined whether 8-month-olds were able to solve the task by learning a rules such as "look back in the opposite direction to that of movement". Their study involved two main conditions whereby the infant had to turn in either the same direction as the rotation or in the reverse direction to locate the event site on test trials. The results showed no significant difference between the two conditions when no landmarks were present.

Experimental Environment

Keating et al. (1986) examined infants' performance in a circular room as well as in a square room. The two types of room shape provide two different types of environment; the square room has distinctive, visual features (i.e., four corners) and the circular room has no such visual features. The circular room can therefore be considered a completely featureless environment. Such a visually impoverished environment assesses infants' egocentric abilities because infants have to rely on their egocentric abilities alone.

A comparison of infants' performances in these two types of room showed that infants perform better in the square room than in the circular room. Keating et al. (1986) conclude that 8-month-old infants are able to use even subtle environmental features (i.e., the corners of a square room) to locate a hidden event. This finding confirms that it is necessary to use a circular room when measuring infants' egocentric abilities.

Training Regime

So far this review has examined research that has trained infants to look towards the event site before the adult appears (i.e., anticipatory training). This method of training an anticipatory response with a cue often requires many training trials; such training continues until infants reach an adequate level of anticipatory looking. During training, infants are therefore required to repeat trained looking responses numerous times. The continued repetition of these looking responses during training may add to infants' inability to inhibit a previously successful response. Diamond (1990) explains that young infants have difficulty inhibiting a previously successful response. This likelihood may increase response perseveration (repetition of a trained response) on test trials. Decreasing the number of times a response is repeated during training may help to reduce the likelihood of response perseveration in young infants.

It is therefore possible that the occurrence of response perseveration in the studies by Acredolo (1978) and Keating et al. (1986) was increased by the use of anticipatory training. The "peek-a-boo" event need only be associated with the presenting of the cue: the event need not be associated with a particular response.

Tyler and McKenzie (1990) compared the performances of 8-month-old infants trained using this method of association (refered to as *associative training*) with infants trained using anticipatory looking method (refered to as *instrumental training*). From this comparison it would be possible to examine the effect anticipatory training may have on infants' looking responses during test trials, thus determining whether infants are sensitive to such training methods.

Infants in the anticipatory training group were trained in the same way as those in Keating et al.'s (1986) study—they were therefore only moved to the next position once they reached an adequate level of anticipatory looking. Infants in the associative training group were trained to associate the appearance of the adult (i.e., the event) with a cue (a flashing light directly ahead). Once infants attended to the light, it stopped flashing and the adult appeared immediately. Only two trials occurred at each of the two training positions.

Performance on the test trials showed that the number of 8-month-old infants (out of 12) who relocated the event site was 11 and 2 for the associative and anticipatory training groups, respectively. These results indicate that infants are significantly more accurate at the task with the associative training method than with the instrumental training method.

In this study, the use of associative training also enabled younger infants to succeed; seven out of 12 infants aged 6 months successfully relocated the event site; demonstrating a moderate level of successful performance. Previous research which used anticipatory training found much lower levels of performance in 6-month-olds (e.g., Rieser, 1979). The use of associative training may provide a more accurate picture of infants' ability to keep track of movements which are more complex.

Lew, Bremner, and Lefkovitch (2000) continued with the use of associative training, but moved infants around the perimeter of a circular enclosure—a movement involving both rotation and translation; a more complex type of movement than that used by Tyler and McKenzie (1990). The study examined the egocentric abilities of 6-, 8.5-, and 12-month-olds. Their results showed that infants at the two younger ages, 6 and 8.5 months, were unsuccessful at relocating the event site. Only at 12 months were the majority of infants successful. Taken together, these findings suggest that the task may be made more difficult for infants to solve with the use of a more complex movement; one involving both rotation and translation as opposed to rotation only.

However, research subsequent to that of Tyler and McKenzie (1990) using a rotation only movement has failed to support such high level of accuracy among infants. Bremner and Hatton (1996) report only a moderate level of successful performance with 6- and 9-month-olds.

Summary

From the research looked at so far in this review, it is evident that findings on infants' spatial abilities are mixed. However, it is clear that the type of procedure used to assess their abilities added to this heterogeneity: Acredolo (1978) showed that infants are first successful at around 16 months; this is much older than the age found in more recent studies. These later studies perhaps show a more accurate picture of infants' spatial orienting abilities. Such studies adapted the task, improving it on its aptitude to measure infants' spatial abilities.

So far three points of methodological consideration are highlighted. First, it is essential to use more than one training position: when only one is used infants are susceptible to response conditioning. Second, it is important to use a featureless, circular room to accurately examine infants' egocentric abilities: infants are able to use even subtle environmental features (such as those provided by the shape of a room). Third, it is necessary to associate the appearance of "peek-a-boo" with a cue: the continued repetition of looking responses during training (prevalent with the anticipatory training method) may lead to response perseveration in young infants.

Allocentric Spatial Coding

Allocentric coding, as mentioned in the introduction, is the ability to use visual features to code the location of a hidden object or event. Research assessing infants' allocentric abilities therefore adds distinctive features (i.e., landmarks) to the experimental environment, and compare performance in this environment with that in which no such features are added. Better performance in the landmarked environment, compared to the non-landmarked one, indicates evidence of allocentric coding.

Depending on their form, these visual features can provide a visual network or frame, a single indirect relationship to the event's location, or a beaconing effect (whereby a distinct visual feature directly marks the location of the event). If a strictly functional definition of allocentric spatial coding is used, then the number of landmarks necessary to code the location of a goal unambiguously depends on the situation. If the position of the landmark is contiguous with the goal, only one landmark is necessary. Such a landmark is commonly refered to as either a proximal cue (Rudy, Stadler-Morris, & Albert, 1987) or a beacon (e.g. Whishaw & Dunnett, 1985). Because the representational and computational implications of using two or more landmarks in a relational way are different from those involved in using a beacon, the term allocentric coding is reserved for situations in which two or more landmarks are needed to locate a goal, and the term *beaconing* is used to denote the case of orienting to a single landmark (for a review presenting the distinct neuropsychobiological bases for the different spatial coding strategies, see Nadel, 1990). The neuropsychobiological basis for allocentric coding is addressed in Chapter 2.

Infants' abilities with regard to these three types of allocentric coding are presented separately.

Multiple Landmarks Forming a Frame

As addressed in the previous section on the egocentric spatial coding strategy, Keating, McKenzie, and Day (1986) examined infants' abilities to use visual features, such as those provided by the shape of the room, to locate the hidden "peek-a-boo" event. Allocentric coding was possible in the square room, but not in the circular room, because its four corners provided a visual frame of reference. Keating et al.'s results confirm this possibility: infants in a square room perform significantly better than those in a circular room. These findings indicate that 8-month-old infants are able to use visual features—presented as a network or frame—to successfully relocate a hidden event.

Hermer and Spelke (1994) found that older infants (18 to 24 months) use the geometric shape of a room to reorientate themselves and often ignore the room's non-geometric properties. This finding demonstrates that when disorientation occurs at this age, the use of a frame of reference provided by the shape of an environment predominates over the use of direct landmarks.

Indirect Landmarks

Another form of allocentric coding examined is infants' ability to use visual features as indirect landmarks. In this situation it is necessary that infants are able to learn the relationship between the landmark (or landmarks) and the location of the event. The learning of this relationship is used to relocate the hidden event after being moved to a new position. This type of allocentric coding requires infants to use this learnt relationship to update their previous locating response based upon the landmark.

In Acredolo and Evans' (1980) study, the non-event window (situated opposite the event window) was framed by lights and coloured stripes. The event window remained unmarked. The results from this study showed that, with the addition of the indirect landmark, 11-month-olds were significantly more successful at relocating the event window, but the 6-month-olds performed poorly, continuing to look towards the non-event window. However, the 9-month-olds began to show no clear success or failure response: instead, mixed responding predominated (they turned to both windows, first looking to one and then to the other). This type of responding among the 9-month-olds indicates that this form of landmarking had some effect; the infants were no longer looking towards the wrong window as expectantly as they had when both windows were unmarked.

These results suggest that the presence of an indirect landmark aids infants' ability to successfully relocate the correct window at 11 months. The younger infants are not yet helped by the presence of such landmarking; the 6-month-olds less so than the 9-month-olds.

Rieser's (1979) study of spatial abilities in 6-month-old infants included a condition in which the target door was indirectly landmarked. In this condition, the target door remained unmarked and the other doors were distinctively patterned. Infants at this age were unable to relocate the event door and responded in the same way they had when all the doors remained unpatterned.

However, Rieser's (1979) results are not surprising considering that the 6-month-olds in Acredolo and Evans' (1980) study were also unaided by the presence of indirect landmarks. It is perhaps only older infants who are aided by the presence of indirect landmarks; thus it is possible that this type of allocentric coding ability emerges later in development.

The study by Lew et al. (2000) examined infants of a wider age range: 6-, 8.5-, and 12-month-olds. The location of the "peek-a-boo" event remained unmarked, but two visual features were added to the perimeter of the circular enclosure: an orange lantern was placed on one side of the event site and a black lantern on the other side.

With this indirect landmarking of the event site, 6-month-olds performed as poorly as they had done when such landmarks were absent, and the 12-month-olds performed as highly. The 8.5-month-old infants performed significantly better than they had when landmarks were absent, implying that these landmarks aided their ability to successfully relocate the event site. These findings suggest that infants become able to use such indirect landmarks at around 8.5 months.

A Beacon (Direct Landmarking)

The third type of landmarking to be examined is infants' abilities to use a single, distinctive visual feature placed at the event site. This type of landmarking provides direct visual information regarding the event's location. It is the most direct form of landmarking; no indirect relationship between it and the event site needs to be learnt. It seems that, after moving to a new position, directing one's behaviour towards the landmark results in successfully relocating the hidden event.

With the use of this most direct form of landmarking, it may be possible to demonstrate evidence of the allocentric coding ability in younger infants (i.e., in infants younger than 8.5 months); it would uncover the age at which the ability to use this type of spatial coding strategy emerges. This simplest form of allocentric coding is the ability to use a *beacon.*

In Acredolo's (1978) beacon condition, a bright yellow star surrounded the event window. Acredolo studied the abilities of 6-, 11-, and 16-month-olds. The findings from this study indicate that at 11 months infants are able to use this form of landmarking to locate the correct window. At 6 months infants continued to look towards the non-event window (a similar pattern of responding as they had shown when no beacon was present) and at 16 months, infants performed well in conditions both with and without the beacon.

In a later study, Acredolo and Evans (1980) increased the saliency of the beacon. In this salient condition, the event window was surrounded by flashing lights and the wall was covered with large orange and black diagonal stripes. With this form of salient beaconing, both the 9- and 11-month-olds accurately located the event window; the 6-month-olds showed evidence of mixed responding. These levels of successful performance are much higher than those reported in the earlier study involving a less salient beacon condition (i.e., Acredolo 1978).

Keating et al. (1986) studied the ability of 8-month-olds to use a beacon in both a square and a circular room[3]. Although infants in the square room performed better than those in the circular room, the interaction between room shape and beacon did not prove to be significant. Half the infants in the circular room were able to use the beacon to successfully locate the event.

Tyler and McKenzie (1990) used the associative training method to examine the performance of 8-month-olds in a beacon condition. They found a much higher level of successful performance than had Keating et al. (1986) (11 out of 12 infants looked towards the event site). However, infants at this age also performed at ceiling level in the no beacon condition. The 6-month-old infants were not tested in a beacon condition. These younger infants may have shown an improvement in their performance with the presence of a beacon; this would have provided evidence of beacon use.

It is possible that the improvement in performance shown in the tasks by Keating et al. (1986) and Tyler and McKenzie (1990) compared to those by Acredolo may have been due to the difference in the extent of rotation as opposed to the difference in the type of movement used (i.e., the former used rotation only, whereas the latter used both rotation and translation). The degree of rotation used in the former studies was of a lesser extent than that used by Acredolo who used 180^0. The extent of rotation may have been an important variable in the level of task performance. However, Cornell and Heth (1979) found that 8-month-olds were able to search correctly on an object search task following movements involving a 180^0 rotation.

A recent study looked at beacon use in 6- and 8.5-month-olds (Crowther, Lew, & Whitaker, 2000; Study 1).[4] Although infants at 8.5 months showed an improvement in their performance when a beacon was present, those at 6 months showed no improvement. However, the lack of improvement at 6 months may have been due to the

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[3] McKenzie, Day, and Ihsen (1984) examined performance with 6- and 8-month-olds but did not include a control group for the younger age group. They reported high levels of performance at these two ages, but see earlier comment on comparability, pp. 13.

use of a more complex movement (one involving both rotation and translation) as opposed to a less complex one (involving rotation only, as used by Tyler and McKenzie, 1990). With a less complex movement, it may be possible to show evidence of beacon use in these younger infants.

Using a modified version of the "peek-a-boo" task, McKenzie, Day, Colussa, and Connell (1988) compared movements involving either rotation or translation and found no significant difference in the level of performance at 8 months. However, using an object search task, Landau and Spelke (1988) included a condition that used a movement involving both rotation and translation and found that 9-month-old infants performed worse with these movements combined relative to either rotation and tranlation on their one. With a less complex movement, it may be possible to show evidence of beacon use in these younger infants.

Is beacon use a spatial strategy?- Evidence from comparative studies on beacon use.

Comparative studies have revealed that specific regions of the brain are fundamental to the use of visual features in forming spatial representations (e.g., hippocampal and parietal areas of the cortex; O'Keefe & Nadel, 1978). It has also been found that rats with lesions to these brain regions are able to solve a spatial task when a visual feature (a beacon) is present (a single landmark—e.g., the object itself or an object suspended just above it; for a review see Nadel, 1990) but are unable to solve the task without this visual feature present. This finding highlights not only a distinction between the use of visual features as beacons (single landmarks) and their use as map-like representations (multiple landmarks) but also the existence of distinct neural bases for each use: one use depends on the function of a certain region of the brain and the other use does not.

The discovery of this dichotomy between the use of a single landmark (a beacon) and the use of more than one landmark implies that it is likely that the two types

[4] This study is not included in the present thesis.

of strategy are not the same. Thus it is unlikely that beacon use is a simpler form of allocentric coding.

This evidence from comparative developmental research indicates that beacon use is a different strategy that has its own neural basis. This finding has led to the consideration that beacon use is a non-spatial strategy; tasks whereby a beacon is present can be solved in a non-spatial way. Tasks that require the use of a beacon can be solved by merely directing one's attention to the beacon. Such tasks do not depend upon the ability to form spatial representations; this ability is necessary when using more than one visual feature in a relational (map-like) fashion.

However, the method used to examine beacon use in studies involving rats is different from that used in infant studies. In the rat studies, the beacon marks the goal location—as in infant studies (see, e.g., Crowther et al., 2000; Lew et al., 2000; Acredolo, 1978). However, in Nadel's (1990) paradigm, the beacon is moved around together with the goal location. This type of search task actively discourages the formation of spatial representations; it can only be solved by using the beacon as a non-spatial associative strategy. Thus, with this type of method, the formation of any spatial representation involving the beacon is made impossible.

In the infant studies, this continuous moving of the goal location between trials does not occur; the location of the goal event (location of "peek-a-boo") remains the same. This form of search task can be solved in one of either two ways: by the infant directing his or her behaviour to the beacon (i.e., using the beacon to guide behaviour—as in the rat studies), or by forming a spatial representation using the beacon. This latter way of solving the task is possible because the goal location (the event site) remains in the same place. It is possible that, during the training trials, infants form some sort of spatial represention as to the event's location; therefore it is possible that they use a spatial strategy to relocate the event—that is, they are not merely directing their behaviour to the beacon. Because of this possibility, the infant studies examining beacon use cannot be excluded from providing evidence of spatial ability.

The Habituation Paradigm.

Another method used to examine infants' understanding of spatial relations is the habituation paradigm. This type of paradigm is based on the assumption that an infant's level of attention remains high to events that are perceived as new or novel (i.e., to events that are different to those already experienced). These already experienced events are refered to as previously encoded events. Therefore, if an infant's level of attention decreases, then it is possible to conclude that the infant detects no novelty in the present event; the event is perceived as no different from the previously encoded event.

These changes in the infant's level of attention provide insight into the form of internal representation used to encode the event. It is possible to establish what the infant is able to encode about the event by changing aspects of it for subsequent presentations.

Using this particular paradigm, Baillargeon (1986) obtained evidence demonstrating that both 6- and 8-month-old infants show location memory using coincident objects (i.e., objects associated to the location of another). In this task infants dishabituated to an impossible event of a moving object apparently going through another object obstructing its path of movement, thus demonstrating that they possessed knowledge that the two objects occupied the same location.

A recent study by McDonough (1999) found evidence that 7-month-old infants are able to remember the location of an object hidden in one of two visually distinctive containers. Infants were also able to remember the location if they were moved and then returned during the delay. This study thus provides evidence that infants this young are able to use visual features to code the location of a hidden object.

Other studies show proficiency in using this type of coding strategy to emerge much later in infancy, at around 9 months (e.g., Bremner, 1978a). A possible reason why studies using the habituation paradigm are able to show such levels of proficiency in younger infants is due to the procedural set up provided by this particular paradigm. This type of set up may be more appropriate for examining the abilities of younger infants than other procedural set ups. The paradigm used by McDonough (1999) removed possible influences of motor and looking response learning: infants were not required to provide any reaching response, and looking exclusively to one location was controlled for.

Although studies using the habituation paradigm provide clear evidence that, at around 7 months, infants are able to code the location of a hidden object using distinctive visual features, these tasks do not measure infants' spatial orientation abilities. Infants in these tasks were not reoriented. However, Kaufman and Needham (1999) recently found evidence indicating that 6.5-month-olds dishabituate on a paradigm involving reorientation. In this paradigm, performance was compared between conditions in which either the infant and/or the object was reorientated. Infants showed evidence of dishabituation only if there was a change in the object's actual location; thus demonstrating the ability to both code an object's position and keep track of self movement.

Summary

Research concerning the onset of egocentric coding abilities shows that, at around 12 months, infants are able to monitor complex movements, those involving both rotation and translation (Lew, Bremner, and Lefkovitch, 2000). Some research shows evidence of its emergence among younger infants, at 8 and even 6 months with a simpler form of movement (involving rotation only; Tyler & McKenzie, 1990). However, there is doubt over this younger age of competency: other research fails to support such high levels of performance (Bremner & Hatton, 1996).

The age of competency with regard to the onset of allocentric coding abilities is younger than that for egocentric coding. There is evidence that infants can use subtle features as a frame or network at 8-months (Keating et al., 1986). The ability to use visual features as indirect landmarks seems to emerge around 8.5 months (Lew et al., 2000). Nonetheless, it is important to note that this ability has not been examined using a less complex form of movement. There is evidence of competency with beacons in infants around 8 months (Tyler & McKenzie, 1990; Crowther, Lew, & Whitaker, 2000). However, research has so far failed to examine beacon use in younger infants using the simpler movement of rotation only.

CAUSAL EXPLANATIONS FOR THE EMERGENCE OF ALLOCENTRIC CODING

After examining the development of infants' abilities on spatial orientation tasks, it follows to understand the process of this development: to examine why, and more important, how this development occurs.

As seen in the previous section, infants begin to be able to use an egocentric coding strategy at around 12 months for movement involving rotation and translation (Lew et al., 2000)—this is evident from spatial orientation tasks in which no visual features are available—and they begin to use an allocentric coding strategy earlier, at around 9 months (Acredolo & Evans, 1980; Bremner, 1978b; Lew et al., 2000)—this is evident from spatial orientation tasks in which direct visual features are available (e.g. a beacon). Infants younger than these two ages—11 and 9 months—fail on the two types of task (on egocentric and allocentric tasks, respectively).

Infants' failure on these tasks suggests that they are unable to update their looking response from those performed during training. Taken spatially, these errors in looking can be explained as resulting from their lack of ability to use the appropriate spatial coding strategy, and conversely that, the change to an accurate looking response can be explained as the emergence of the ability to use the appropriate spatial coding strategy. Improvement in their performance on these spatial orientation tasks can therefore be taken as a demonstration of the development in spatial cognition during infancy.

The development of spatial coding therefore seems to begin with the ability to code, and remember, an object's location relative-to-self. This is referred to as the *relative-to-self response*. However, at this age, whenever the infant is moved, he or she is not yet able to update this coding response in order to take account of the movement—hence infants' ability to stay spatially oriented is poor; this is illustrated by their poor performance on spatial orientation tasks. At around 12 months their ability to stay oriented becomes proficient. Infants at this age can update their previous response to take account of their movement, even without the aid of visual features (i.e., when no visual features are available); 12 months is therefore seen as the age at which the ability to use an egocentric coding strategy emerges.

This review concentrates on examining the process involved in the emergence of allocentric spatial coding strategies.

To summarize.

Research findings put the emergence of this ability at around 9 months (Acredolo & Evans, 1980; Bremner, 1978a &1978b; Lew et al., 2000). Following the identification of the age at which this ability emerges, researchers started to think about why infants begin to use allocentric coding at this particular age.

The Crawling Hypothesis

A theory to explain why the ability to use an allocentric coding strategy emerges at this particular age is based on the fact that infants also begin to crawl at around 9 months on average. With the emergence of this new skill, it is proposed that crawling may be linked to the ability to use visual features to stay oriented (i.e., to use an allocentric coding strategy). This hypothesis has been proposed by Acredolo (1978, 1985, 1990), Bremner (1985), Bremner and Bryant (1977), and more recently by Campos, Anderson, Barbu-Roth, Hubbard, Hertenstein, and Witherington (2000). Before reviewing empirical evidence from recent research, it is important to present the reasons why crawling is proposed as a fundamental causal factor underlying the emergence of the ability to use an allocentric coding strategy.

A way to approach this issue is to begin by outlining the requirements of an allocentric coding strategy for locating a hidden object or event. This coding strategy requires individuals to do three things: (a) attend to the visual features; (b) code the hidden object's location relative to such features; and (c) after reorientation, base one's response on that coding relative to the visual features.

The onset of independent locomotion (i.e., crawling) may increase infants' awareness of their surroundings, and more important, this increase in awareness may be used to solve spatial problems that were not so prevalent before the infants began to crawl.

Functional and Attentional Arguments

Theoretical support for the crawling hypothesis originates from two lines of argument. The first is a functional argument and the second is an attentional one.

The functional argument.

The functional arguement states that, because infants who are not yet able to crawl are less mobile compared to those who are, locating desired objects is easy—no movement results in no need to stay orientated; hence there is no need to use an allocentric coding strategy. However, when infants begin to crawl they also begin to realise that reproducing the same action (i.e., the one produced before moving) no longer results in successfully relocating the object. Hence crawling infants realise that it is vital to adopt another strategy to relocate the object—a strategy appropriate for their new status. Thus, rather than relying on the reproduction of a previous response, crawling infants begin to use visual features in the environment (i.e., allocentric spatial coding).

The attentional argument.

The attentional argument states that crawling improves spatial abilities indirectly; bringing about a significant change in another ability, namely attention. Supporters of this argument believe that attention is crucial in order for any development in spatial ability to occur.

The possible link between crawling experience and visual attention was studied by Horobin and Acredolo (1986). From their research, Horobin and Acredolo noted that, for the crawling infants, "keeping-an-eye" on objects—and the places to which they disappear—is an effective way to find them again when crawling about. However, there is more to the role of attention than simply "keeping-an-eye". Horobin and Acredolo suggest that this method of visually tracking spatial locations may act as a transitional strategy, and is used by infants as they learn what information from themselves and the environment they must attend to in order to establish accuracy in using egocentric and allocentric coding strategies.

Campos et al. (2000) provide a comprehensive review and reanalysis of existing research which examines the consequences self-produced locomotion (crawling) has on the developmental changes in the use of spatial coding strategies. Campos et al.'s overall point of view, on the causal link between crawling experience and developmental change, is that the onset of crawling is a major life transition; the transition involves changes in many psychological domains (e.g., perception, social and emotional development, referential gestural communication, wariness of heights, the perception of self-motion, distance perception, spatial search, and spatial coding strategies). This section concentrates on Campos et al.'s proposal regarding the development of spatial cognition.

Campos et al. (2000) state that crawling is not, in itself, the causal agent; rather it is a skill which brings about new experiences, and that it is these experiences which brings about developmental change. However, the authors believe that, although crawling is a crucial agent in developmental change, it is neither necessary nor sufficient to bring about such change. Because of this interpretation, their proposal accounts for why, in the case of some infants, crawling is not necessary to bring about prominent developmental change.

Campos et al. (2000) put forward four situations whereby crawling may be unnecessary in bringing about the development of new skills (such as the ability to use an allocentric coding strategy).

1. *Partial accomplishment.* The new skill is already present and crawling experience is important in its advancement, but not in its emergence.

2. *Precocious exposure.* The crucial process, normally produced by crawling, is acquired by something else, hence the new skill may be present prior to the onset of crawling.

3. *Equipotentiality*. The new skill occurs through an altogether different pathway; thus the developmental process is different from that produced by crawling.

4. *Maintenance by experience*. The role of crawling lies in updating the new skill and in preventing degradation (caused by no-use), but it does not lie in inducing the new skill.

Campos et al. (2000) suggest a further reason to explain why crawling may be insufficient in evoking developmental change: Crawling may require a crucial subskill. Without this crucial subskill, crawling cannot evoke any form of transition in ability. This suggestion explains why some crawling infants do not appear to have undergone the specific developmental change.

Taken collectively, these reasons as to why crawling is both unnecessary and insufficient in evoking developmental change also explain why some infants develop the new skill (such as the ability to use allocentric coding) without being able to crawl; these reasons explain why the new skill develops in some precrawling infants but not in some crawling infants. Such reasons are important to the crawling hypothesis because without them the theory would falter when research reports such data. Even though the theory behind the hypothesis allows for the occurrence of evidence demonstrating that crawling is sometimes unnecessary or insufficient in evoking developmental change, it does however expect the two variables (i.e., crawling and developmental change) to be correlated in a significant number of cases.

A theory stating that crawling plays a fundamental causal role in the development of spatial abilities should also, to validate its claims, be able to explain why spatial abilities are poor in comparison to before the onset of crawling.

The review by Campos et al. (2000) elaborates on the functional and attentional arguments put forward by earlier researchers (e.g., Acredolo, 1978; Bremner, 1994). The review also identifies possible constraints on the behaviour of precrawling infants. These constraints impair their abilities both at a functional and at an attentional level. The authors outline why spatial abilities in precrawling infants are poor, and hence why crawling occasions developmental change by enabling them to overcome such constraints. These constraints on precrawling infants are as follows: They are only exposed to limited experiences (such as sitting, turning, and reaching) and unable to use distal landmarks because their targets are less distal. Following the onset of crawling, infants overcome such constraints; Campos et al. (2000) explain that overcoming these constraints enables the development of the allocentric spatial coding strategy (the ability to use visual features in the environment).

The following section examines the array of empirical evidence and attempts to establish whether there is support for the crawling hypothesis.

Research Examining the Link Between Crawling and the Development of Spatial Abilities

Research examining this link has used both visual search and manual search tasks. Although visual search tasks are most applicable to this thesis (as such tasks examine spatial orientation skills in large-scale space) findings from manual search tasks are also reviewed; this is because the majority of research is centred around this type of task.

The research examined in this review that uses visual search tasks are based on the paradigm devised by Acredolo (1978). This type of search task takes place in a square room which has two windows positioned on opposing walls; the infant is seated at one end of the room, between the two windows. During several training trials the infant is required to anticipate the appearance of an adult at one of the windows (referred to as the event window) following an auditory cue. Following the training trials, the infant is moved to the opposite end of the room, and only the auditory cue is given—the adult does not appear. Success on the task requires the infant to look towards the event window.

When the event window is distinctively landmarked using visual features (e.g., with a bright yellow star and coloured stripes across the wall) the findings demonstrate the ability to use a beacon.

The research examined in this review using manual search tasks are based on the AB search task, a paradigm first devised by Piaget (1954). In the standard AB search task, the infant is seated in front of two reachable locations (referred to as locations A and B). During several training trials, a toy is hidden at location A and the infant is required to reach and retrieve it. Following these training trials, the toy is moved and hidden at location B. Success on the task requires the infant to reach and retrieve the toy when it is at location B. Variations of this manual search task include moving the infants around to the other side of the table (e.g., Butterworth, 1977; Bremner & Bryant, 1977), rotating the table (e.g., Bai & Bertenthal, 1992; Bell, 1992; Roberts, Bell, & Pope, 1998; Bremner & Bryant, 1977), and visually distinguishing the two locations (e.g., Bremner 1978a; Telzrow, Campos, Shepherd, Bertenthal, & Atwater, 1987; Telzrow, Campos, Kermoian, & Bertenthal, 1999). These latter tasks are not strictly AnotB as the toy is sometimes not moved and hidden at location B.

Spatial Search Tasks

Various methods have been used to examine the role crawling may play in evoking developmental change. These methods involved comparing the spatial abilities of precrawling infants with those of crawling infants, comparing the abilities of infants with varying lengths of crawling experience, and manipulating either the early or the late onset of crawling to observe the influence on spatial ability.

The findings from visual and manual search tasks are presented separately and divided into the following subsections: (a) precrawling versus crawling, (b) length of locomotor experience, (c) enrichment, and (d) deprivation. At the end of this presentation, and before a summary, one further issue is discussed: the role of attention.

Precrawling versus crawling.

This method compares the performances of two groups of infants: those who are not yet crawling (the precrawling group) with those who are crawling (the crawling group). Age is often kept constant in such research: infants are tested at the same age. If crawling is the important causal factor in the emergence of improved spatial abilities, then infants in the crawling group should perform significantly better than those in the precrawling group.

Visual search.

Two studies, carried out almost in parallel to each other, examined the link between crawling and the onset of allocentric coding by comparing the performance of precrawling and crawling infants in a landmarked condition—whereby the event window was marked by a salient visual feature (Enderby, 1984; Bertenthal, Campos, & Barrett, 1984). Both studies produced similar findings.

In Enderby's (1984) study, 36-week-old infants were divided into either a precrawling or a crawling group. It was found that infants in the crawling group performed significantly better on the task than those in the precrawling group. This finding was replicated by Bertenthal, Campos, and Barrett (1984).

The findings from these two studies appear to strengthen the theory that there is a link between crawling and improved spatial coding strategy, particularly in the emergence of the ability to use landmarks (i.e., allocentric coding).

Manual search.

Kermoian and Campos (1988) compared the spatial abilities of precrawling and crawling infants on a series of manual search tasks based on the standard AB search task. After comparing the performances of infants in both groups, it was found that infants in the crawling group were significantly better at the tasks than those in the precrawling group.

Length of locomotor experience.

If crawling is linked to improved spatial abilities, then infants with more crawling experience should perform better than those with less crawling experience.

Studies which attempted to establish whether this is the case compared the spatial abilities of infants with varying lengths of crawling experience.

Visual search.

A study, also carried out around the same time as those of Enderby (1984) and Bertenthal et al. (1984), examined the link between crawling experience and improved spatial search (McComas & Field, 1984). The spatial abilities of infants with two weeks crawling experience were compared with those of infants with eight weeks crawling experience. Infants were tested in a landmarked condition of the search task—that is, a yellow star surrounded the event window. The results indicated no link between crawling experience and successful performance: the performance of infants did not differ significantly between the two groups. McComas and Field concluded that their results did not add support to the hypothesis that crawling experience brought about development in allocentric coding.

A reason for the lack of improvement in spatial ability reported by McComas and Field (1984) may be the type of landmark used. Other studies, which report a significant effect of crawling experience (Bertenthal, Campos, & Barrett, 1984; Enderby, 1984), used a more salient form of landmarking—a large yellow star together with stripes and flashing lights. Without these additional salient features, it is possible that the task in McComas and Field's study was more difficult for infants to solve.

However, a criticism of the methodology used by McComas and Field's (1984) throws doubt on the validity of the conclusion that their results did not add support to the crawling hypothesis. McComas and Field's study comprised only crawling infants; no precrawling infants were included. The exclusion of precrawling infants as a baseline group would diminish any possible significant improvement in performance produced by crawling; this is because such improvement would only become apparent if their performance is compared to that of a precrawling group.

It is possible to establish whether or not this criticism of McComas and Field's (1984) methodology is valid by comparing their results with those of a similar study which did include a precrawling group. Enderby's (1984) study is one such study. The two studies report similar levels of successful performance in their crawling groups—40% and 50%, respectively. The similarity in the performance between these two groups leads one to infer that the level of success reported by Enderby's precrawling group (15%) would possibly have been replicated by McComas and Field if they had included a precrawling group. It is therefore possible that, if McComas and Field had included a precrawling group (as a baseline comparison to the crawling group), then their conclusion would be to the contrary.

This comparison between the two studies also diminishes the possibility that the poor results reported by McComas and Field (1984) are explained by the lack of landmark saliency. McComas and Field reported an almost identical level of performance in their crawling group to that by Enderby (1984); yet Enderby used the more salient form of landmarking.

Manual search.

Kermoian and Campos (1988) found that length of locomotor experience did play a significant role in the improvement of spatial abilities. However, they also found that the improvement produced by crawling goes through a transitional phase. When Kermoian and Campos (1988) reexamined the performances of infants in their crawling group, it was only those infants with nine weeks or more experience who showed a significant improvement in performance compared to those in the precrawling group; those infants with only one to four weeks experience showed a no significant improvement in performance compared to those in the precrawling group.

This analysis, examining the length of crawling experience, suggests that a period of transition exists between five and eight weeks experience regarding performance on such search tasks (Kermoian & Campos, 1988). The possibility of a transitional phase may also explain why McComas and Field (1984) reported no significant difference in the performance of infants in their two and eight weeks crawling experience groups: the group with eight weeks experience may not have passed through the necessary transitional phase, and thus would not have shown a significant improvement. However, it seems unlikely that this possibility is sufficient to explain why McComas and Field reported no influence of experience. Bertenthal et al. (1984) and Enderby (1984) both reported a significant improvement in the performance of the crawling group compared to the precrawling group; it is unlikely that infants in the crawling group had more than the eight weeks crawling experience necessary for the improvement to be brought about from this transitional phase because all infants in this study were 36 weeks old—for these infants to have had this length of crawling experience, they would all have had to have been very early crawlers indeed (i.e., around two months earlier than on average). This period of transition may be task specific; thus it may only apply to manual search tasks.

Enrichment studies.

An interesting manipulation, carried out by some studies comparing precrawling and crawling infants, is the inclusion of a third group (Bertenthal, Campos & Barrett, 1984; Enderby, 1984; Kermoian & Campos, 1988). This extra group consists of precrawling infants; it is therefore equal, on a maturational level, to the standard precrawling group (i.e., both these groups comprised infants who are not yet able to crawl). However, infants in this third group are qualitatively different from those in the precrawling group; these infants are given the opportunity to experience self-produced locomotion through the use of babywalkers. This enrichment group consisted of a non-random selection of infants; parental choice determined baby-walker use.

If the performance of this precrawling-with-babywalker group is significantly better than that of the standard precrawling group, then it can be said that the important component linked to improved performance is the *experience* crawling produces (i.e., self-produced-locomotion). However, if the performances of these two groups are equal, then the important component is the *ability* to crawl, or some other, related factor.

Visual search.

In both studies (Bertenthal et al., 1984; Enderby, 1984) the level of performance of infants in the enrichment group (i.e., precrawling-with-babywalker group) was significantly better than that of infants in the precrawling group; it was also comparable to that of infants in the crawling group. The comparison of this third group with the other two (precrawling and crawling) groups demonstrates that the experience gained from the babywalkers is equivalent to that gained from crawling in terms of spatial performance.

Manual search.

Kermoian and Campos (1988) also included an enrichment group (precrawling-with-babywalker group) in their study. Kermoian and Campos's findings showed that precrawling infants in this babywalker group performed significantly better than those in the precrawling group, and that their level of performance was equal to that of infants in the crawling group.

The evidence produced by these enrichment studies shows that the spatial abilities of precrawling infants, when given the opportunity to experience self-produced locomotion (such as through the use of a babywalker), can equal those of crawling infants. This evidence highlights the possible role played by the experience gained through crawling in the development of spatial abilities. However, because of the non-random selection of infants to the baby-walker group, other factors influencing their performance cannot be ruled out (such as differences in the developmental expectations of parents who choose to use babywalkers).

Deprivation studies.

The evidence produced by enrichment studies, indicating a link between independent locomotor experience and improved spatial ability, can be strengthened if evidence produced by deprivation studies also indicates such a link. In deprivation studies, the onset of crawling is either delayed or non-existent. If it is shown that improvement in spatial ability is also delayed or non-existent and, importantly, that following the restart of crawling, spatial performance improves, then such findings strengthen the crawling hypothesis.

Visual search.

One deprivation study, which used the paradigm devised by Acredolo (1978), is a case study of an orthoepedically handicapped infant (Bertenthal, Campos, & Barrett, 1984). The infant was born with congenitally dislocated hips and, after an early operation, placed in a full body harness. This harness halted the normal development of mobility and thus prevented crawling. The infant was tested on the visual search task once a month, beginning at 6 months and ending at 10 months. During this time the harness was removed. The results showed that the infant's performance was poor until the harness was removed and the infant had begun to crawl. These findings support the notion that crawling is causally linked to the development of spatial ability.

There are two criticisms of this study. The first arises from the problem inherent in most case studies: that is, the difficulty of generalizing the findings. The second is specific to this study, and directly weakens its main conclusion. This specific criticism relates to the fact that crawling was delayed for only a few weeks longer than that of the average onset. Hence it is difficult to conclude that the delay in this study was large enough to constitute deprivation. The onset of crawling in this infant could have been normal (i.e., not due to deprivation). This possibility significantly weakens the main conclusion made by the study; that is, that crawling is the fundamental causal link in the development of spatial ability. In order to state such a conclusion, the onset of crawling should be delayed by a much longer period.

Manual search.

Research carried out with Chinese infants—who, for cultural reasons begin crawling on average 3.3 months later than the norm set by the Bayley's Scale of Infant

Development (Bayley, 1969)—showed crawling experience to have a significant effect on improved task performance (Toa & Dong, 1997).

However, although this study assessed infants delayed in the onset of crawling by 3.3 months, it is not a true deprivation study. Infants were only tested at various intervals after the onset of crawling, and not before. Without a comparison of performance before and after onset, it is not possible for these findings to have the same impact as those from deprivation studies.

Another set of studies tested performance both before and after the delayed onset of crawling (Telzrow, 1990; Telzrow, Campos, Shepherd, Bertenthal, & Atwater, 1987; Telzrow, Campos, Kermoian, & Bertenthal, 1999). Telzrow and his colleagues tested seven infants with spina bifida on the two location search task devised by Bremner (1978b)—whereby both locations were visually distinct, and the toy was always hidden at A—and found search performance to improve after infants began crawling. This finding suggests a delay in crawling also brings about the delay in improved search task performance, thus adding support to the theory linking crawling to improved spatial search abilities. However, because of the small sample size, this conclusion must be taken with caution.

Attention

An interesting observation noted by Telzrow et al. (1999) was that when infants begin to crawl, their attention towards the task increased; infants became less distracted and more task focused. The important role played by attention in improving spatial abilities is also brought up in earlier studies (e.g., Horobin & Acredolo,1986; Bai & Bertenthal, 1992). However, Horobin and Acredolo conclude that attention towards the task is a better predictor of improved performance than crawling. This evidence supports the idea that any beneficial effect of crawling on spatial performance is mediated through attention.

Crawling may improve spatial task performance by enhancing infants' attentional abilities. This possibility, regarding the important role of attention, relates to findings produced from the enrichment studies; precrawling infants, through the use of babywalkers, can show levels of spatial performance equivalent to those of crawling infants. This improvement in the performance of precrawling infants can be explained by the enhanced levels of attention the babywalker provides.

A related issue is the role of *active* versus *passive* movement. The movement experienced by infants in the two types of locomoting (i.e., the crawling and precrawling-with-babywalker) groups is under their own control, and is therefore *active*; conversely the movement experienced by infants in the precrawling group is under the control of someone else (e.g., being carried by a parent) and is therefore *passive*. The information gained from the experience of these two forms of movement—active and passive—is also *actively* and *passively* driven, respectively. The types of information produced by the two movements may create a division in the levels of attention employed during movement.

Active movement allows active exploration of the environment. Exploratory behaviours require attention to be direct towards goal locations. Because exploratory behaviour is actively driven, levels of attention are high throughout such active movement. Some studies have shown that crawling infants who experienced either self-initiated (active) movement performed better than crawling infants who experienced other-initiated (passive) movement during the task (Acredolo, Adams, & Goodwyn, 1984; Benson & Uzgiris, 1985)

A further point explains that it is the high levels of attention during such active movement that produce better spatial performance, rather than the *active* (i.e., self-produced) movement. This point can be clarified by examining evidence from research concerning the spatial abilities of bellycrawlers. Bellycrawlers are infants who are able to actively move about by themselves (i.e., capable of self-produced-locomotion); however, they are not yet able to move around on their hands and knees. These infants thus have similar capabilities to those infants in the crawling and the precrawling-with-babywalker groups. They are therefore less maturationally advanced than infants in the crawling group.

Kermoian and Campos (1988) examined the spatial abilities of a group of bellycrawlers on a series of manual search tasks. Their results show that bellycrawling infants perform at a level equal to that of precrawling infants. So, although these infants are able to *actively* move about (similar to infants in the crawling and precrawling-with-babywalker groups), their performance remains at the same level as those infants not yet able to crawl (i.e., precrawling infants).

The level of attention deployed is different between the types of locomotion experienced by bellycrawlers and by precrawlers-with-babywalkers; but more importantly *where* it is deployed. Because bellycrawlers do not have the multilimb coordination of crawlers, moving around is a strenuous activity. Bellycrawling is thus an effortful form of locomoting. For the bellycrawlers, their attention is focused on the task of moving, whereas, because the crawlers (and the precrawlers-with-babywalker) are able to move about more freely, and are much less encumbered in moving, they are able to attend to their surroundings. These findings further highlight the role attention plays in the improvement of spatial abilities.

Alternative Causal Explanations

Although the main focus of this thesis is the link between crawling and the development of spatial abilities, it is important not to ignore explanations which focus on alternative links. This section highlights the two main alternative causal explanations for the development of spatial abilities.

This section considers two lines of explanation: brain maturation as a causal factor, and an interactionalist approach. The basis of the first line of explanation demonstrates the development of spatial abilities as being independent from crawling. The second line of explanation acknowledges both brain maturation and crawling as factors, but presents the main causal factor as being the interaction between the two.

The first part of this section focuses on the suggestion that specific regions of the brain are fundamental for spatial cognition; hence the development of spatial abilities is dependent upon the maturation of these brain regions. This part presents evidence from research into the development of spatial abilities in non-human subjects.

The second line of explanation is based on a recent rethinking of the development of spatial ability. This explanation accepts the influence of both brain maturation and behavioural development (i.e., the onset of crawling). The rethinking presents a picture involving new ideas on the development of spatial abilities. It presents the development of spatial abilities as being the result of an interaction between brain maturation and crawling.

Neuropsychology of Spatial Cognition

Spatial cognition is not a function unique to humans; it is a function also possessed by non-human animals. Knowledge and understanding about the development of spatial cognition in humans is enhanced by examining findings from equivalent studies with non-humans. Such comparative research often provides a level of insight into spatial development that research with infants does not. Examining the role brain regions play is an area of investigation studied more extensively in research with animals than in research with infants. This area of investigation aims to uncover the regions of the brain (neural structures) necessary for spatial cognitive functions.

One region of the brain uncovered as an area fundamental to spatial cognition, particularly for the ability to use visual cues relationally, is the hippocampus (O'Keefe & Nadel, 1978). The hippocampus is a neural structure situated in the medial temporal lobe of the brain (Squire, 1982). Research has shown that this region of the brain is involved in a specfic type of memory (Hirsh, 1974; Gaffan, 1974; O'Keefe & Nadel, 1978; Olton, Becker, & Handelmann, 1979), such as when arbitrary elements are bound together to form an episode (i.e., episodic memory; for a review see Squire, 1992). Lesions to this region have no effect on other forms of learning—classical conditioning, for example, Cohen, 1984; Squire, 1992. This evidence of hippocampal function is also apparent in humans (e.g., the case of patient HM; see Scoville & Millner, 1957). This evidence is from patients with damage to right hippocampal and parietal cortex areas of the brain. The research shows that these patients are able to carry out certain tasks that require spatial cognition, but their abilities are limited.

Much understanding about the development of spatial abilities has been gained from studies examining rats. These studies follow the development of a rat's ability to solve various tasks requiring specific spatial abilities. Rat pups are useful animals to examine; they undergo extensive postnatal brain maturation, as do human infants.

The paradigm used by Morris (1982) is a task used extensively in rat research to measure spatial abilities. In this task, the rat is placed in a circular tank of water containing a submerged platform.The water is opaque (i.e., milky in appearance); therefore the submerged platform is hidden from view. To locate the submerged platform, the rat is required to use an array of visual features. The rat is placed at different starting positions around the perimeter of the tank. To find the platform, it is therefore necessary for the rat to form some sort of representation of the platform's location, irrespective of its own starting position.

It was shown that the ability to use visual features (allocentric coding) to locate the submerged platform required normal hippocampal function (Morris, Garrud, Rawlins, & O'Keefe, 1982). Rats without a functional hippocampus—that is, those with hippocampal lesions—were unable to relocate the submerged platform. This finding therefore suppports the view that the hippocampus is a brain region fundamental in the ability to use of an allocentric spatial coding strategy.

Development of Both Spatial Ability and Hippocampal Function

Nadel (1990) also examined hippocampal maturation and the development of rats' spatial abilities by following the daily progress of a group of rat pups (for a period of several weeks) using Morris's (1982) watermaze paradigm.

Rats are mobile soon after birth (at around two to four days); this is important because it refers back—and is connected—to the crawling hypothesis. Rat pups are able to move around the environment a few days after birth. This ontogeny of mobility in rats is very different from that of humans. Human infants become mobile (i.e., begin crawling) at a much later stage of development. If the crawling hypothesis were to be extended to other species in accounting for the development of spatial abilities, then animals mobile from an early age (such as rats) should show evidence of competent spatial abilities at around this time also.

Nadel's (1990) study ascertained that rat pups perform poorly on the watermaze task, and continue to perform at this same level for some time. This finding refutes what would be expected if the crawling hypothesis is accurate in other species; it suggests that the formation of spatial abilities is dependent upon more than just locomotion—as these rat pups were able to locomote. The transition to competent performance on the spatial task occurred around postnatal Day 21. Nadel's finding provides evidence to support the idea that the ability to move around does not in itself instigate, or bring about, improvement in spatial abilities. When each rat's behaviour was analysed in detail, possible clues were revealed that may help to explain the transition to a competent level of task performance. This analysis concentrates on investigating the emergence of another complex function: exploratory behaviour (Kurz & Nadel, unpublished—see Nadel & Willner, 1989). Each rat was monitiored from postnatal Day 17 to Day 25. This analysis revealed that the transition in the level of performance on the spatial task coincides with the emergence of exploratory behaviour; This suggests that, although rats are mobile soon after birth, they do not demonstrate typical exploratory behaviours during this early period of mobility. Instead, rats take direct routes to desired locations and show no evidence of exploring the environment. These findings by Nadel and his colleagues add emphasis to the role of exploratory behaviour in the development of spatial abilities and make a clear distinction between locomoting around the environment and actively exploring it.

Nadel (1990) noted that it was also around this time when rat pups begin to show significant hippocampal maturation (as indexed by growth of dentate gyrus cells; see, e.g., Seress & Mrzljak, 1992). This finding suggests the hippocampus as a brain region correlated with the emergence of exploration; the emergence of exploratory behaviour therefore seems to be related to hippocampal maturation. Taken together, these findings support the idea that hippocampal maturation plays a role in the emergence of exploratory behaviour, and in turn, they highlight the importance of exploration in the development of spatial abilities.

The emphasis on the significance of exploratory behaviour for the development of spatial abilities revealed from comparative studies is a finding which, if explored in humans, may provide more explanation to the development of spatial abilities in human infants. This significance of exploratory behaviour may explain why some crawling infants are poor at spatial tasks; these infants, though crawling, are not yet exploring, and vice versa—why some infants who are not yet crawling are good at spatial tasks; that is, those infants who, though not yet crawling, are exploring. The emphasis on the importance of exploratory behaviours for developing spatial abilities allows for this dichotomy in the spatial abilities between some crawlers and some precrawlers; this emphasis states that it is the onset of exploration that is important, not crawling.

These comparative studies also show a commonality between the brain regions involved in exploration and spatial cognition. Some recent comparative research shows that rats possess cells within the hippocampus that are activated when the rat is in a particular location in the environment; these cells are referred to as "place" cells (O'Keefe & Nadel, 1978). Findings that are possibly more applicable to human spatial cognition come from research examining the composition of the hippocampus in non-human primates. This research shows a high concentration of cells that are activated by the visual display of particular spatial arrays irrespective of viewing position (Rolls & Treves, 1998). This latter finding suggest a dominance regarding visual exploration as opposed to active (locomotor) exploration.

Interactionalist Model

This final section presents recent work by Newcombe and Huttenlocher (2000); their ideas on the development of infants' spatial abilities are based on a recent review of the infancy literature regarding spatial cognition. Before presenting their ideas on *how* development takes place, this section outlines their ideas about *what* is developing—an area where Newcombe and Huttenlocher present a rethinking of previous ideas.

The aim of this literature review, and the focus of this thesis, is to examine when allocentric coding emerges, that is, to examine when this ability emerges in infancy. This focus therefore views allocentric coding as an ability that, through development, infants acquire. Newcombe and Huttenlocher (2000) view development in a different way. In their view, infants begin life possessing all the spatial coding strategies; thus each strategy does not emerge during the infant's development. However, Newcombe and Huttenlocher accept that changes do occur in infants' performance on spatial tasks during development; but instead of viewing these changes as the emergence of the infant's acquisition of a new coding strategy, they view them as the emergence of the infant's ability to use the appropriate strategy: Thus they view development as a process whereby the infant learns which spatial coding strategy to use in which situation. Evidence of failure on the spatial task is therefore considered as demonstrating the infant's inability to use the appropriate strategy in the particular situation, rather than demonstrating the complete absence of a particular strategy.

This theory by Newcombe and Huttenlocher (2000) is considered an alternative to the crawling hypothesis; this is because the crawling hypothesis regards crawling as important in establishing the capacity to carry out such a coding strategy, whereas Newcombe and Huttenlocher state that the allocentric coding strategy does not need to be established; the strategy is present from birth.

In explaining how infants' spatial abilities develop, Newcombe and Huttenlocher (2000) include the role of general experience and do not restrict experiental input to crawling alone. They view experiental inputs as necessary to generate positive and negitive feedback; both forms of feedback help the infant to learn which strategy to adopt in which situation—for example, to learn when it is necessary to rely on visual features (i.e., to use an allocentric coding strategy).

Newcombe and Huttenlocher's (2000) interactionalist view also accepts brain maturation as a relevent factor in infants adopting the use of the appropriate strategy, although they appreciate that the attribution of this to development is not yet clear.

Some research has found that crawling infants show an increased level of maturation in frontal and occipital regions of the brain relative to precrawling infants (Bell & Fox, 1996). However, crawling may be a reflection of this level of maturation rather than its cause; that is, crawling may not bring about significant changes in cognitive function.

The process of brain maturation may be driven by the experience crawling infants go through. This alternative view is advocated by some researchers, particularly Thelen and Smith (1994) and Thelen (2000). Only Campos et al. (2000) make an explicit link between crawling and allocentric coding. Other versions of the crawling hypothesis focus on paying attention to visual flow as a marker of self movement (e.g., Bremner, 1994) and the value of monitoring the goal location throughout self-movement (e.g., Acredolo, 1990). Newcombe and Huttenlocher (2000) acknowledge the existence of a complex interaction between experiental and brain development as a causal factor bringing about developmental change.

This recent proposal, generated by Newcombe and Huttenlocher (2000), advocates an explicitly interactionalist approach between crawling and brain maturation in spatial development.

AN OUTLINE OF EXPERIMENTAL CHAPTERS

This thesis has two aims. The first aim is to establish whether infants younger than 8.5 months are able to use an allocentric spatial coding strategy. This is addressed by a series of cross-sectional studies (Studies 1, 2, & 3). These studies consider methodological adaptions to the standard spatial orientation task (which uses the "peek-a-boo" paradigm). These adaptations concentrate on the type of movement used to reorientate the infant (Study 1), the type of training regime, and the saliency of the beacon (Study 2). The final cross-sectional study (Study 3) is a full methodological replication of Tyler and McKenzie's (1990) study.

The second aim is to examine whether crawling is linked to the emergence of the ability to use an allocentric spatial coding strategy. This is addressed by a longitudinal study (Study 4). This study monitors the development of both spatial task performance and motor abilities (e.g., the onset of crawling).

SPATIAL ORIENTATION ABILITIES IN 6- AND 8.5-MONTH-OLD INFANTS AFTER A ROTATIONAL DISPLACEMENT

Research has found that the ability to use landmarks to code the location of a hidden event (an allocentric spatial coding strategy) emerges when infants are around 8.5 months (Acredolo & Evans, 1980; Bremner, 1978a; Keating, McKenzie, & Day, 1986; Lew, Bremner, & Lefkovitch, 2000). Lew et al. (2000) found that 8.5-month-olds performed better in a landmarked conditon than in a non-landmarked condition; this suggests that at this age infants are unable to use an egocentric spatial coding strategy, but that they are beginning to be able to use an allocentric spatial coding strategy. The theory put forward to explain the emergence of allocentric coding proposes that crawling—an ability which emerges around 8 to 9 months—is the main causal factor driving this developmental change in infants' spatial abilities.

Six-month-old infants in Lew et al.'s (2000) study performed poorly in both the non-landmarked and landmarked conditions. This finding suggests that infants at this age are unable to use both an egocentric and an allocentric spatial coding strategy.

Tyler and McKenzie (1990)—who examined the performance of 6- and 8-month-old infants using a similar task, but who only examined their performance in a non-landmarked condition—reported an almost ceiling level of performance at 8 months (with 11 out of 12 infants locating the event site) and a moderate level of performance at 6 months (with 7 out of 12 infants locating the event site). Both these levels of performance are much higher than those reported by Lew et al. (2000).

Tyler and McKenzie (1990) did examine task performance in a beacon condition, but with 8-month-old infants only. The experiment found equal levels of performance between the two conditions; levels in both conditions were near ceiling (with 11 out of 12 infants in each condition locating the event site). However, because the 8-month-olds were already performing at ceiling level in the non-landmarked condition, it was not possible for them to show any improvement in the landmarked condition.

On the other hand, it is possible that the 6-month-olds may have shown an improvement in the landmarked condition; these infants did not perform at ceiling level in the non-landmarked condition. An improvement would demonstrate the ability to use allocentric coding at this younger age.

Highlighting methodological differences between Lew et al.'s (2000) study and Tyler & McKenzie's (1990) study may help to explain why the two studies found much different levels of performance.

Both studies trained infants to associate a cue with the appearance of an adult at a fixed location (the event site) from several positions, and tested infants from a new position, whereby only the cue was given, and the adult did not appear. However, the location of the infant's position during the procedure differs between the two studies. In Lew et al. (2000)'s study, the infant is situated at the perimeter of the enclosure, and is moved around the perimeter to the different positions. In Tyler and McKenzie's (1990) study, the infant is situated in the centre of the enclosure, and is rotated to face different directions. Therefore, even though both studies require the infant to make similar responses to locate the event site (that is, turn to the left and right), the type of movement used to move the infant to these positions is different. Moving the infant around the perimenter of the enclosure involves both rotation and translation; therefore the infant experiences not only a change in his or her orientation but also in his or her position. Moving the infant at the the centre of the enclosure involves rotation only; therefore the infant only experiences a change in his or her orientation. The movement used in Tyler and McKenzie's study is therefore simpler than that used in Lew et al.'s because it does not involve a translation. The complex movement (of rotation and translation) used by Lew et al. may explain why the levels of performance were much lower than those reported by Tyler and McKenzie: It may be more difficult for 6- and 8-month-old infants to keep track of movements which involve both rotation and translation than those which involve rotation only.

Some researchers connect this developmental progression—in the capability to take account of increasingly more complex movement—with the concurrent development in postural and motor abilities; taking account of bodily rotation is connected with gaining control over trunk rotation (the onset of independent sitting) and taking account of bodily displacement is connected with gaining control over body displacement (the onset of crawling) (e.g., Bremner, 1994).

When no landmarks are present (as in a non-landmarked condition) the task is solved using an egocentric spatial coding strategy. This spatial coding strategy requires coding the event site relative to oneself and keeping track of one's own movement in order to relocate it after movement. Because the absence of landmarks requires the need to keep track of one's own movement, it may be easier to relocate the event site in tasks that use a simple movement than in those which use a more complex movement. The method employed by Lew et al. (2000) may have underestimated infants' allocentric coding abilities due to its use of a more complex movement (i.e., one involving both rotation and translation).

Lew et al. (2000) report a significantly higher level of performance at 12 months compared to 6 and 8.5 months in the non-landmarked condition; thus confirming that 12-month-olds are more capable of keeping track of this complex movement than 6- and 8.5-month-olds. It appears that as infants get older they become increasingly capable of keeping track of this complex movement.

It may be possible to find an improvement in the level of performance with infants younger than 12 months in a non-landmarked condition by adapting the method employed by Lew et al. (2000) to involve a simpler movement. If the use of a simpler movement in a non-landmarked condition results in an improvement in the level of performance, it would confirm that younger infants are more capable of keeping track of this simpler movement than the more complex one. Tyler and McKenzie (1990) report a slightly higher level of performance at 8 months than at 6 months. This finding indicates that 8-month-old infants are more capable at keeping track of a rotational movement than 6-month-old infants.

If evidence can be found to show that task performance increases when a simpler movement is used, then it leaves open the possibility that later investigations with landmarks may show evidence of landmark use in infants younger than 8.5 months. This would clearly confirm the ideas developed by Campos et al. (2000) that crawling is not a necessary condition for landmark use to emerge.

It is possible that a further methodological difference between Lew et al.'s (2000) study and Tyler and McKenzie's (1990) made some contribution to the different levels of performance reported by each study; this difference concerns the number of trials used to train the infant to associate the cue with the appearance of the adult. Lew et al. used four trials, whereas Tyler and McKenzie used six. The use of more training trials results in the infant experiencing the event and cuing on more occasions. This added experience may improve task performance by helping the infant to code the two incidences (i.e., the cue with the appearance of the adult at the event site).

This present study[5] modifies the method used by Lew et al. (2000) to involve a simpler movement (rotation only rather than rotation and translation) and more training trials. It is predicted that, with a simple movement (one involving rotation only) and two extra training trials in a non-landmarked condition, the level of performance at both 6 and 8.5 months will be higher than that reported by Lew et al.; also the level of performance at 8.5 months will be higher than that at 6 months.

[5] The original aim of this study was to compare the levels of performance between two movement conditions; one that used rotation and translation, and another that used rotation only. However, after running infants in the simpler movement condition, it became evident from the levels of performance observed that running the more complex movement condition would be ineffectual; the levels of performance in the simple movement condition were too low for there to be any improvement from levels in a more complex movement condition. As a result, performance in only one movement condition was examined—the condition involving a rotation only movement.

Method

Participants

Participants were recruited through parents volunteering in response to advertisements in the local paper and leaflets displayed in local health clinics. Only infants born between 37 and 43 weeks gestation were included in the sample. Additionally, infants that did not make a response within 2 seconds on either test trial (see Design section) were excluded from the final sample.

Two groups of infants took part in the study: one group of 6-month-olds and one group of 8.5-month-olds. Each group contained sixteen infants. The group of 6-month-olds (M = 24 weeks, 6 days; SD = 6 days) comprised seven males and nine females. Six further infants were tested: four were excluded because they failed to respond on both test trials; one was excluded because he became upset; and one was excluded because of experimenter error. The group of 8.5-month-olds (M = 36 weeks, 4 days; SD = 6 days) comprised eight males and eight females. Three further infants were tested but were excluded because they failed to respond on both test trials.

Apparatus

The experimental setting was a circular enclosure 200 cm in height and 230 cm in diameter (see Figure 3.1). The circular effect of the enclosure was obtained by attaching eight curtains to a circular frame and suspending the frame from the ceiling of an outer room. Where the curtains joined each other, they formed eight slits: One slit was the entrance (and was sprung shut during the procedure), and one slit was the event site (through which the experimenter appeared during the "peek-a-boo" phase). The other six slits were kept shut.

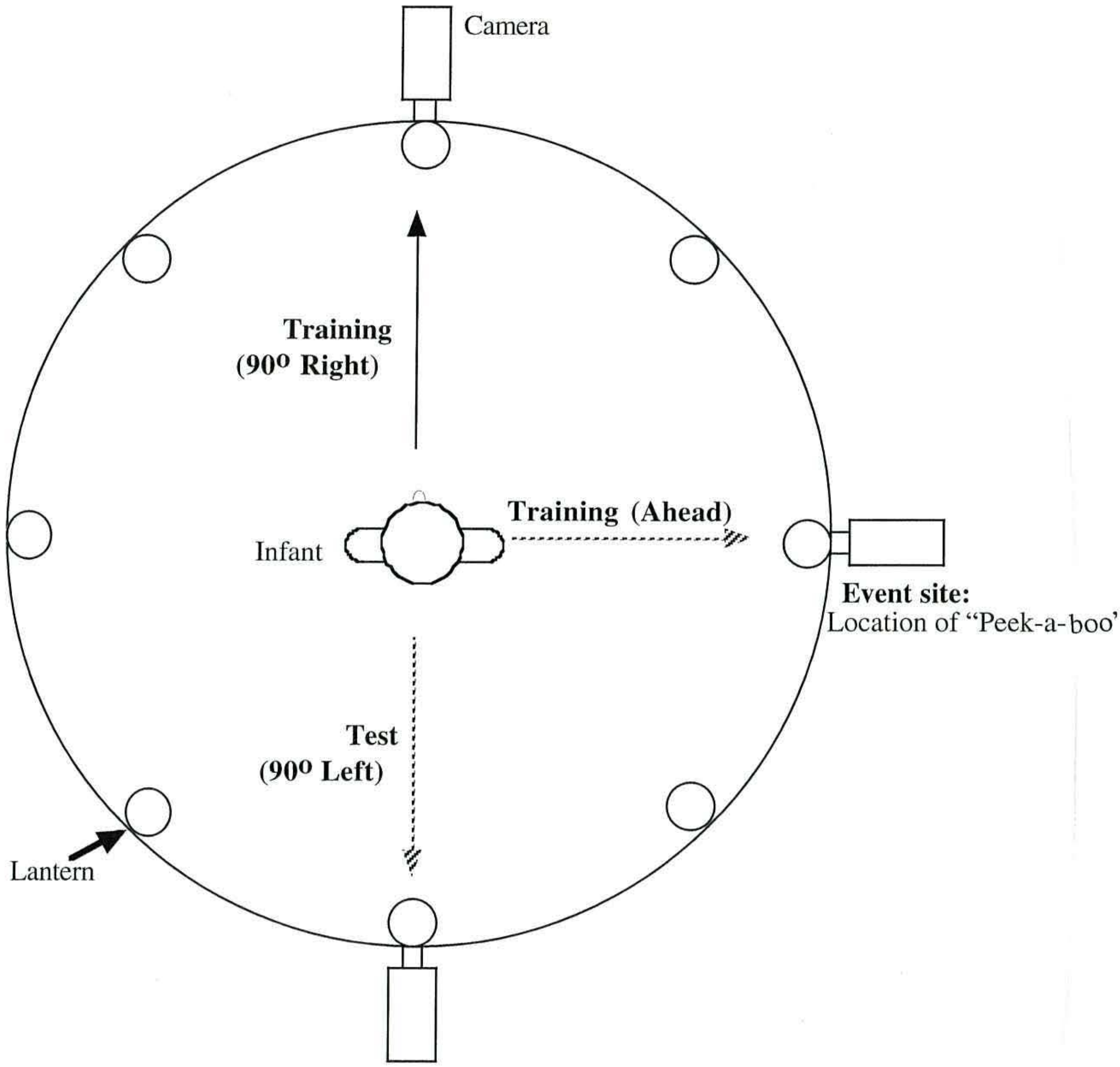

Figure 3.1. The experimental enclosure with the infant facing the direction of the 1st training position. Also dipicted are the directions of facing for the 2nd training position and test position.

At equal intervals around the perimeter of the enclosure (corresponding to each slit) a lantern was hung 25 cm from the ceiling. Each lantern was 45.5 cm in length and 27 cm in diameter and the same colour as the curtain material.

Lighting inside the enclosure was obtained from a single light situated in the centre of the ceiling.

A sound source, which emitted an auditory signal (250 Hz, 3 v peak to peak amplitude, and 0.68 s duration) situated in the centre above the ceiling of the enclosure, was operated remotely by the experimenter.

Three video cameras were fixed to the outside frame of the enclosure and were positioned at infant eye level. The camera lenses protruded through holes in the curtains. Five mock camera lenses were positioned at equal distances around the perimeter of the enclosure; this made the camera lenses indistinguishable—this added to the uniform appearance inside the enclosure. The three video cameras provided frontal views of the infant from each direction of facing.

Each camera was channelled to a split screen video system; this allowed observation of the three camera views simultaneously. The television monitor was positioned outside the enclosure and could be seen by the experimenter from the event site; this enabled the experimenter to monitor the infant's behaviour throughout the procedure. The video system was equipped with slow motion and frame by frame control to be used in behavioural analysis.

The infant sat in an upright baby-seat (one used in cars) mounted on a trolley; the trolley was moved by the parent who stood behind the seat. The infant's eye level was at a height of 75 cm from the floor.

Design

The spatial orientation task comprised of six training trials and two test trials. During the six training trials, the infant was trained to associate an auditory cue with the appearance of the experimenter at a set location (the event site) from two directions of facing (ahead and 90° either right or left—see Figure 3.1). The infant was positioned in the centre of the enclosure and rotated to face the different directions. The order of the directions of facing (training positions) alternated pseudorandomly—within constraints that there were three trials from each position—infants were rotated back and forth between the positions (e.g., Training Trials 1, 2, and 6 from one training position and Training Trials 3, 4, and 5 from the other training position). The sequence of the training positions was calculated randomly for each infant.

After the training trials, the infant was rotated to face a new direction; the two test trials followed in which the experimenter did not appear after the auditory cue. The infant's looking response following the auditory cue was recorded and used as an indicator of where the infant expected the experimenter to appear.

The test position faced 90° in the opposite direction of the event site to that of the training side—that is, to the 90° position of facing.

Half the infants were tested facing to the left and half were tested facing to the right. Infants tested to the right were therefore trained from positions facing 90° left and ahead of the event site, those infants tested to the left were trained from positions facing 90° right and ahead of the event site.

Procedure

Prior to the procedure, a period of familiarisation (lasting five minutes) took place inside the enclosure. The experimenter talked through the procedure with the parent while the infant played with toys. This period of familiarisation allowed both the parent and the infant to become comfortable with the experimental setting.

During the procedure, the parent stood behind the baby-seat and rotated the infant to face the different directions. The infant sat in the baby-seat at the centre of the enclosure. The positions of rotation were discretely marked on the floor and were specific for each sequence. Before training began, the parent rotated the infant several times at the centre of the enclosure and stopped with the infant facing the direction required for the first training trial. The rotation before training was carried out in order to disorientate the infant with respect to the entrance.

The following procedure describes the sequence of positions outlined in the design section above (for an illustration, see Figure 3.1), that is, 90° right and ahead during training, and 90° left during testing.

At the first training position (90° right) Training Trial 1 took place; the auditory cue (a buzzer) sounded and the experimenter appeared (at the event site) through the slit in the curtains, entertaining the infant verbally. The appearance of the experimenter (referred to as the *"peek-a-boo" phase*) lasted 15 seconds. At the end of the "peek-a-boo" phase, the experimenter disappeared from view by closing the curtains. Training Trial 2 took place from the same position.

After Training Trial 2, the parent rotated the infant to the second training position for Training Trials 3, 4, and 5. From the second training position (ahead of the event site) the same auditory cue and "peek-a-boo" phase pattern ocurred. Training Trial 6 took place back at the first training position (90° right).

After the training trials, the parent rotated the infant to the test position—a new direction of facing (90° left) to the event site. From this position, Test Trial 1 and Test Trial 2 followed. On each test trial, the auditory cue sounded but the experimenter did not appear. A 10 second interval separated the two test trials. The procedure ended 10 seconds after the auditory cue on Test Trial 2.

Inter-Trial Intervals

The procedure contained seven inter-trial intervals (five in between the six training trials, one before, and one between, the two test trials). The inter-trial intervals during training and the one before Test Trial 1 were calculated by measuring the length of time (in seconds) from the end of the "peek-a-boo" phase (when the curtains closed) on the previous training trial to the start of the auditory cue on the next trial. The inter-trial interval between the two test trials was calculated by measuring the length of time (in seconds) from the end of the auditory cue on Test Trial 1 to the start of the auditory cue on Test Trial 2. The inter-trial intervals ranged from Mean 8.19 (SD = 2.4) seconds to 11.31 (SD = 3.09) seconds. The aim was to have these as near to 10 seconds as possible. There was no significant difference between the two age groups regarding the length of the inter-trial intervals. Variations occurred due to the need to sound the buzzer when the infant was not already looking in the direction of the event site.

Behavioural Scoring

The video cameras enabled observational analysis of each infant's behaviour on the test trials. Two measures of behaviour were recorded: the *location* and the *latency* of the infant's first look from the beginning of the auditory cue. The infant's first look had to be made within a designated time window. This time window began from the start of the auditory cue and ended two seconds after the auditory cue finished; this was approximately 2.68 seconds (including the length of the auditory cue—0.68 seconds). A first look made after the time window was scored as a *no response*.

The infant's first look was defined as the first change in visual fixation following the onset of the auditory cue (this included anything from a brief change involving eye movement only to a change involving both eye and head movements). Any look to the event site within 4 seconds following the onset of the auditory cue was also recorded—*any look to target (within 4 seconds)*—as the infant may have some knowledge as to the event site's location without making a first look to it.

For each test trial , the location of the infant's look prior to the auditory cue was coded as one of three categories; these were *opposite*, *ahead* and *other* (for a definition of each category see section below).

Location of first look.

The location of the infant's first look was coded as one of five categories: *target*, *undershoot*, *ahead*, *opposite*, and *other*.

The codes are defined using looking ahead as 0°. Looks in the direction of the event site are referred to using positive degree angles, and looks in the opposite direction referred to using negative degree angles.

Target: between +60° and +90°.

Undershoot: between +10° and +60°.

Ahead: between -10° and +10°.

Opposite: between -10° and -90°.

Other: a direction not defined by the other four codes (this includes looks that are either down to the floor, at their straps, up at their parent, or up to the ceiling).

Latency of first look.

The latency of the infant's first look was defined as the time taken (in seconds) from the start of the auditory cue to the beginning of the change in visual fixation.

Inter-Observer Agreement

An inter-observer agreement check was carried out using 40% of the data set (26 test trials). These test trials were randomly selected within the constraints of having roughly equal numbers of each category of the five location categories from each test trial (*no response* and *other* were collapsed into one category as there was only one trial classified as *other*). The second observer was blind to the experimental condition. A Cohen's kappa (Cohen, 1960) of agreement was performed on the full set of response categories for location of first look. The level of agreement obtained was .89. The mean difference between observers for the latency of first look was .24 seconds (4.5 frames), $SD = .35$ seconds (approximately 8 frames). Only those trials in which both observers had scored a response were used for this analysis of latency agreement.

Results

Table 3.1 shows the number of first looks made to each location category for each age group. To examine the difference in the level of successful performance between the two groups, the dependent variable of location of first look was classified as either *correct* or *incorrect*. First looks were classified as *correct* if the location was categorised as *target*, and classified as *incorrect* if the location was not categorised as *target* (i.e., if the location was categorised as either *undershoot*, *ahead*, *opposite*). Locations of first look categorised as *no response* were treated as missing data and were excluded from statistical analysis. An analysis was also carried out on the dependent measure of *any look to target (within 4 seconds).*

Table 3.1. Frequency of first looks to each location category for each age on the two test trials—*any look to target (within 4 s)* in parentheses.

Age	Location of First Look				
	Target	Undershoot	Ahead	Opposite	No Response
Test Trial 1					
6 months	1	3	4	7	1[a]
8.5 months	1 (2)	0	4	8	3 (2*)
Test Trial 2					
6 months	2 (3)	2	3	5	4
8.5 months	2 (3)	0	6	1	7

[a] Includes 1 first look categorised as *Other*.

A preliminary analysis was conducted to confirm that no systematice differences existed between the two age groups in terms of where infants were looking prior to the auditory cue; this analysis examined the location in which each infant was looking prior to the auditory cue on each test trial. A hierarchical model building approach was applied. A binomial distribution of data was presumed and a logit link function was used. Using binary regression analysis, tests of significance were based on log-likelihood ratios and referred to the Chi-square distrubution (two tailed). The dependent variable was first looks classified as *correct*, (that is, categorised as *target*); the factors involved were *Trial* (Test Trial 1, Test Trial 2), *Age* (6 months, 8 months), and *Prior Look* (*ahead, opposite, other*). The first factor included in the model was *Trial.* This was considered the most conservative approach: the main focus of interest were the factors of *Age* and *Prior look* ; this approach removed any main effects due to *Trial* before these factors were considered. In the analysis of *correct* first looks, the factor of *Prior Look* did not yield a significant main effect; this confirmed that *Prior Look* produced no systematic differences between the two age groups.

Subsequent analysis (with *Prior Look* as the dependent variable and with *Trial* and *Age* as factors) confirmed that there were also no significant main effects of *Age* or *Trial* on the location of *Prior Look.*

Location of First Look

As can be seen from Table 3.1, there was no increase in the number of infants who made *correct* first looks in the 8.5 month group compared to the 6 month group on each test trial. This lack of increase suggests that the level of performance (locating the event site) in the 8.5 month group was not higher than that in the 6 month group. These levels of performance are comparable to those reported by Lew et al. (2000), and are much lower than those reported by Tyler and McKenzie (1990)—in which 11 and 7 infants (out of 12) made *correct* first looks, at 8 and 6 months, respectively. Table 3.2 shows the results of the binary regression analysis for *correct* first looks and *any look* *to target (within 4 s)* containing the factors of *Trial*, *Age* and their interaction together with an *Infant* factor

Table 3.2. Effects and significance tests for *correct* first looks and *any look to target (within 4 s).*

DependentVariable	EffectName	df	Chi-Square	p
Correct First Looks	Trial	1	1.69	.19
	Age	1	.12	.73
	Trial X Age	1	.01	.94
	Infant	30	36.8	.25
	Residual	16	.00	1.0
Any Look to Target (within 4 s).	Trial	1	1.75	.19
	Age	1	1.32	.25
	Trial X Age	1	.08	1.21
	Infant	30	41.24	.083
	Residual	17	.00	1.0

(the *Infant* factor determines whether there is consistency of responding between Test Trials 1 and 2). In the analysis of *correct* first looks, there were no significant main effects for each factor or their interaction.

Any Look to Target (Within 4 Seconds)

The second analysis involved measuring the level of performance based on whether infants made a look to the event site within an extended time window of 4 s (refered to as *any look to target (within 4 seconds)*). The results of this second analysis are reported in Table 3.1 (see parentheses).

Even with the use of this more moderate measure of successful performance, the frequency of *correct* first looks increased by only one infant in the 8.5 month group on Test Trial 1 (there was no increase in the 6 month group) and by only one infant for both age groups on Test Trial 2.

The main analysis of *any look to target (within 4 seconds)*, using the same classification of look as used for first look (i.e., as either *correct* or *incorrect*), also revealed no significant main effects for each factor or their interaction.

Latency of First look

The time taken for infants in each age group to make the first look was analysed using a 2 x 2 ANOVA—*Age* was a between subject factor and *Trial* was a repeated measures factor. If the 8.5-month-old infants were faster on average, then such would imply that the time window of 2 seconds designated for first look might have been inappropriate for the 6-month-old infants. However, the analysis revealed that there was no significant difference between the two age groups for the latency of first look; the mean latencies ranged from .77 (SD = .63) seconds to 1.64 (SD = .75) seconds.

Discussion

This study found no significant difference in the level of performance between the two age groups: Infants in the 6-month-old group performed at a level equal to that of infants in the 8.5-month-old group. The hypothesis stating that the level of performance in the 8.5 month group would be higher than that in the 6 month group was therefore not supported. Apart from an equal level of successful performance between the two age groups, the results also show that the level of performance in both age groups was low. These low levels of performance indicate that most infants, at each age, were unable to relocate the event site on test trials. This inablitiy to relocate the event site (i.e., solve the task) suggests that the majority of infants in each age group were unable to keep track of the simple movement—rotation only. Therefore, this study also reports no improvement in the level of performance compared to the use of a more complex movement (e.g., a movement involving both rotation and translation; in comparison to the levels reported by Lew et al., 2000).

Taken together, the results of the present study and those of Lew et al. (2000) indicate that both 6- and 8.5-month-old infants are unable to keep track of movements which involve rotation and translation, and simpler movements—ones involving rotation only. This study therefore does not provide support for the view that the ability to keep track of rotational movements is related to the onset of sitting. Support for this view would have only been provided if the 8.5-month-olds performed significantly better than the 6-month-olds.

The inclusion of two extra training trials was the other modification to Lew et al.'s (2000) study used in the present one. Because no improvement in the level of performance was found between the two studies, it implies that the difference in the number of training trials between Lew et al. and Tyler and McKenzie (1990) does not explain the difference in the levels of performance between the two studies (i.e., the use of more training trials did not aid task performance in Tyler and McKenzie's study).

The similarity between the results of the present study and those of Lew et al. (2000) suggests that it is also unlikely that the difference between the results reported by them and those by Tyler and McKenzie (1990) is due to the type of movement used in each study; Lew et al. used rotation and translation whereas Tyler and McKenzie used rotation only. This present study, which used a type of movement identical to that used by Tyler and McKenzie, reports levels of performance similar to those of Lew et al.; these levels of performance are much lower than those reported by Tyler and McKenzie.

The failure of the present study to show levels of performance comparable to those of Tyler and McKenzie (1990) also has wider implications related to future investigation of landmark use in infants younger than 8.5 months (e.g., 6-month-olds). The similarity between the findings of this study and those of Lew et al. (2000) implies that, if the performance of infants in a landmarked condition is examined, the 6-month-olds would show no improvement compared to the present study (i.e., a non-landmarked study); the levels of performance in Lew et al.'s study were equally low at this young age in both a landmarked and a non-landmarked condition.

The findings from the present study produce the need to investigate other procedural differences between Tyler and McKenzie's (1990) study and Lew et al.'s (2000) study; the procedural modifications carried out in this study failed to provide evidence to explain the different outcomes reported by the two studies.

BEACON USE FOR SPATIAL ORIENTATION IN 6- AND 8.5-MONTH-OLD INFANTS USING A FACILITATING TRAINING REGIME

This study attempts to explain the different levels of performance reported by Lew et al. (2000) and Tyler and McKenzie (1990) by exploring procedural differences between the two studies, that is, other than the type of movement used—as explored in the previous study (Study 1).

In the training regime used by Lew et al. (2000), infants experience the appearance of the event ("peek-a-boo") from two directions of facings: Ahead and opposite to that used in test trials. The use of these two directions not only ensures that infants experience the event from two directions (each position thus requires a different response, lessening the likelihood of encouraging a conditioned response) but also that the response required to relocate the event site on each test trial is unrelated to those required in training. A procedure which ensures that infants are tested from a novel postion (i.e., one requiring a novel response, one different from those required in training) produces a conservative measure of infants' ability to locate the hidden event. The measure is considered conservative because a successful response cannot be the result of response repetition. However, the training regime used by Tyler and McKenzie (1990) does not use an ahead position during training. Two training directions are used: One opposite to that used in test trials (as in Lew et al.'s) and another in the same direction as that in test trials (e.g., the infant is trained from 90° left and 45° right of the event site and then tested from 90° right of the event site). The use of the 45° training position means that the response required in test trials to relocate the event site is similar to that of a previously required response; that is, it is in the same direction as a trained response. The use of this position causes some difficulty when ensuring that the response in test trials is more then merely the repetition of a previous response and that the infant is able to relocate the event site. This type of training regime used by Tyler and McKenzie may facilitate a *correct* first look on test trials; infants are not required to make a completely novel response in terms of the *direction* of their look in this type of training regime. It is unlikely that this facilitating effect occurs in the training regime used by Lew et al. This difference between the type of training regimes used could be the reason why Tyler and McKenzie found much higher levels of successful performance than did Lew et al.

It has been found that previous reponses sometimes influence subsequent ones. Work by Diamond (1985, 1988, & 1990) found that infants are unable to inhibit a prepotent response, thus a subsequent one is the result of response repetition. This finding necessitates a degree of caution regarding the type of training regime used so as to minimise the influence of infants' inability to inhibit previous motor responses. In Tyler and McKenzie's (1990) study, infants who repeat a trained response on a test trial could be seen as successful at the task. This could not be the case in the previous study (Study 1) or in Lew et al.'s (2000) study; the repetition of a trained response would be seen as unsuccessful because locating the event site requires a novel response from the test trial position. Both the previous study (Study1) and Lew et al. report equally low levels of successful performance.

The present study will adopt a training regime similar to that used by Tyler and McKenzie (1990). The regime will thus train infants from both sides of the event site. The use of the ahead training position will be removed and replaced with a training position 45° from the event site in the same direction as the test trial position.

This study will also measure the ability to use a beacon. The use of a more facilitating training regime may increase the likelihood of obtaining evidence of allocentric coding in infants younger than 8.5 months. Crowther et al. (Study 1, 2000) examined beacon use in 6- and 8.5-month-olds and found that 8.5-month-old infants were significantly better at localising the event site with a beacon than the 6-month-old infants. However, levels of performance at each age were low. Not only could these low levels of performance be due to the type of training regime involved, but they could also be due to the type of beacon used. Similar levels of performance were obtained with indirect landmarks for 8.5-month-old infants (Lew at al., 2000). An explanation for this similarity in the levels of performance could be that, while the beacon provides a simpler relation between the event site and the landmark than the indirect landmarks, the degree of simplicity interacts with the degree of visibility. The two painted lanterns (placed either side of the event site) used in Study 1 of Lew et al. might be more visually salient than the single painted lantern used in Study 1 of Crowther et al.

Crowther et al. (2000) found no evidence to show that 6-month-olds were aided by the beacon in relocating the event site. The 6-month-olds may need a more visually salient beacon. This need may reflect a developmental progression with regard to landmark use; as well as an increasing capability to cope with greater complex relations between landmarks and the goal location, there may also be an increasing capability to cope with less visually salient landmarks.

Crowther et al.'s (Study 1; 2000) use of a less salient beacon, the ahead training position, and a more complex movement (i.e., rotation and translation) could be a less appropriate set up for obtaining evidence of beacon use in young infants than one which uses a more salient beacon, trains from both sides of the event site, and uses a simpler movement (i.e., rotation only). It is possible that, with the use of this simpler movement, 6-month-old infants would demonstrate improved performance when a beacon is present relative to a control (no beacon) condition. The present study examines performance with a beacon of increased saliency.

The present study attempts to establish whether 6-month-olds will show an improvement in their level of performance in a beacon condition using procedural modifications similar to those of Tyler and McKenzie (1990). Infants experience the "peek-a-boo" event from both their left and right (e.g., 90° left and 45° right) before being tested in a new position (e.g., 90° right). In addition, a new beacon is used. This was constructed to form a large, coloured hoop, framing the adult's face during the "peek-a-boo" phase; this made the relation between the event site and the beacon more salient than in the case where a painted lantern is placed directly above the adult's head (as in Study 1 of Crowther et al.; 2000). The performance of a group of 8.5-month-olds will also be examined in both the beacon and the no beacon condition. No predictions are made regarding improved performance in the beacon condition for the

8.5-month-olds; Tyler and McKenzie (1990) report a ceiling level of performance in 8-month-olds (11 out of 12 infants locating the event site) even when no landmarks are present.[6]

[6] A preliminary report by Bremner and Hatton (1996) does not find such a high level of performance at 9 months under task conditions similar to those of Tyler and McKenzie (1990). They report 55.5% (10 out of 18) of infants making *correct* first looks (with six out of the remaining eight making first looks categorised as *opposite*).

Method

Participants

Participants were recruited using the same methods as those in Study 1. To be included in the study infants were required to pass the same specified criteria as for Study 1; only infants born between 37 and 43 weeks gestation were included in the sample and, additionally, infants that did not make a response within 2 seconds on either test trial (see Design section) were excluded from the final sample.

Four groups of 16 infants took part in the study: two groups of 6-month-olds and two groups of 8.5-month-olds. There was a *beacon* group and a *no beacon* group for each age group. Each group contained sixteen infants.

The 6-month-olds.

The beacon group (*M* = 24 weeks, 5 days; *SD* = 1 week, 2 days) comprised seven males and nine females. One further infant was tested but excluded because she failed to respond on both test trials. The no beacon group (*M* = 24 weeks, 5 days; *SD* = 1 week) comprised ten males and six females. Four further infants were tested. Two were excluded because they failed to respond on both test trials, and two were excluded because they became upset.

The 8.5-month-olds.

The beacon group (*M* = 36 weeks, 2 days; *SD* = 6 days) comprised ten males and six females. Three further infants were tested. Two were excluded because they failed to respond on both test trials, and one was excluded because he became upset. The no beacon group (*M* = 36 weeks, 3 days; *SD* = 5 days) comprised eleven males and five females. Seven further infants were tested. Two were excluded because they failed to respond on both test trials, three were excluded because they became upset, and two were excluded because of experimenter error.

Apparatus

The apparatus was the same as described previously (for details, see Study 1). However, a beacon was placed at the event site (the location of "peek-a-boo") in the beacon condition. The beacon was a hoop-shaped landmark, coloured in black and orange stripes. The outer diameter measured 90 cm and the inner diameter measured 60 cm. The beacon framed the experimenter's head and shoulders during the "peek-a-boo" phase.

Design

The design followed the same paradigm as that of Study 1. However, there were procedural changes: a beacon condition was added and the ahead training position was replaced by a position facing 45^0 to that of the test position.

The beacon condition used the same enclosure as the no beacon condition, but a beacon was placed at the location of "peek-a-boo" event (see Apparatus section for details).

The new training position faced the same direction as the 90^0 position used in test trials (see Figure 4.1 for details). The order of the training trial positions was pseudorandom and calculated randomly for each infant (as outlined in Study 1). However, the last training trial was always 90^0 in the opposite direction to the test trial position—the new 45^0 position was not used for the last training trial.

Procedure

The following procedure describes the sequence of positions depicted in Figure 4.1. At the first training position (90^0 right) the auditory cue and "peek-a-boo" phase pattern occurred. After two training trials, from this position, the parent rotated the infant to face the second training position, 45^0 left. Training Trials 3, 4, and 5 took place from this position. Training Trial 6 took place at the first training position (90^0 right). After the training trials, the parent rotated the infant to the test position 90^0 left. From this position, the two test trials followed. Only the auditory cue sounded; the experimenter did not appear.

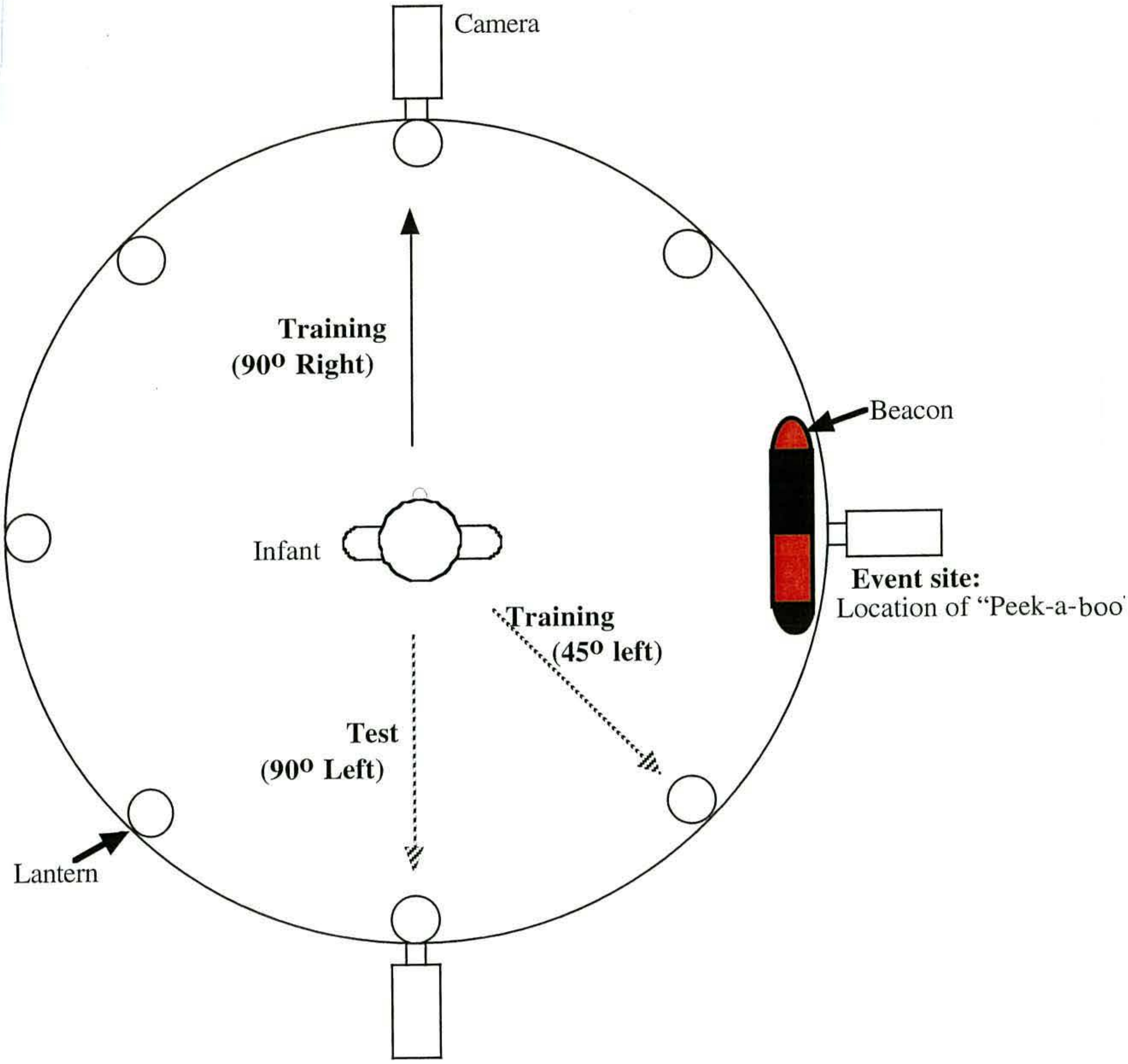

Figure 4.1. The experimental enclosure for the beacon condition with the infant facing the direction of the 1st training position. Also depicted are the directions of facing for the 2nd training position and the test position. In the no beacon condition, the beacon was replaced by a lantern identical to the other seven.

Inter-Trial Intervals

The inter-trial intervals ranged from Mean 9.28 (*SD* = 3.3) seconds to 11.66 (*SD* = 4.96) seconds. There was no significant difference between the four groups regarding the length of these inter-trial intervals.

Behavioural Scoring

The location and latency of first look were scored using the same methods as those of Study 1 (for details, see Study 1).

Inter-Observer Agreement

An inter-observer agreement check was carried out using 40% of the data set (50 test trials). The second observer was blind to which experimental condition was being run. Cohen's Kappa for agreement on the full set of response categories for location of first look was .78. The mean difference between observers for the latency of response measure was .14 seconds (3.5 frames) (*SD* = .44 seconds; 11 frames). Only those trials in which both observers had scored a response were used for this analysis of latency agreement.

Results

Table 4.1 shows the number of first looks to each location category for each age and condition. To examine the difference in successful performance between the groups, the dependent variable of first look location category was classified as *correct* if the location was categorised as *target* or was classified as *incorrect* if the location was not categorised as *target* (i.e., if the location was categorised as either *undershoot, ahead, opposite*). Locations of first look categorised as *no response* and *other* were treated as missing data and were excluded from statistical analysis. The analysis carried out on these data was a 3-way frequency analysis; this was used to develop a logit model of the relation between *Trial* (Test Trial 1, Test Trial 2), *Age* (6 months, 8.5 months) and *Landmark* (Beacon, No beacon). Two separate analyses were carried out. An analysis was also carried out on the dependent measure of *any look to target (within 4s)*; this analysis used the same *correct incorrect* classification.

A preliminary analysis was conducted to confirm no systematice differences existed between the four groups in terms of where infants were looking prior to the auditory cue; this analysis examined the location in which each infant was looking prior to the auditory cue on each test trial. A hierarchical model building approach was applied. A multinomial distribution of data was presumed and a logit link function was used. Tests of significance were based on log-likelihood ratios and refered to the Chi-square distribution (two tailed). The dependent variable was first looks classified as *correct*; the factors involved were *Trial*, *Age*, *Landmark*, and the location of *Prior Look* (*Ahead*, *Opposite*, *Other*). The first factor included in the model was the main effect of *Trial*. This was considered the most conservative approach: The main focus of interest were the factors of *Age* and *Prior Look*; this approach removed any effects due to *Trial* before these factors were considered. In the analysis of *correct*

Table 4.1. Frequency of first looks to each location category for each age and landmark type (*any look to target within 4 s* in parentheses).

Group	Direction of First Look				
	Target	Undershoot	Ahead	Opposite	No Response
			Test Trial 1		
6 months					
no beacon	1 (4)	3	4	7	1[a] (0)
beacon	4 (7)	1	4	4	3 (1)
8.5 months					
no beacon	4 (4)	1	2	9	0 (0)
beacon	6 (8)	0	2	5	3 (0)
			Test Trial 2		
6 months					
no beacon	1 (5)	4	4	5	2[a] (1)
beacon	3 (4)	1	3	6	3 (0)
8.5 months					
no beacon	3 (5)	0	1	6	6[a] (2)
beacon	4 (6)	0	5	4	3 (2)

The number of infants who made a *no response* after 4 s in a test trial for each experimental group is given in parentheses.
[a] Includes a response categorised as *other*.

first looks, the factor of *Prior Look* did not yield a significant main effect; this confirmed that the location of prior look produced no systematic differences between the four groups regarding *correct* first looks. Subsequent analysis (with *Prior Look* as the dependent variable; the factors involved were *Trial*, *Age*, and *Landmark*) confirmed that there were also no significant main effects for *Trial*, *Age*, and *Landmark* on the location of look prior to the auditory cue. This multinomial logistic regression analysis was carried out using SPSS 10.

A preliminary analysis of *correct* first looks included *Sex* (Male, Female) and *Test Trial Position* (Left, Right) as factors, as well as *Age*, *Trial*, and *Landmark*. Neither *Sex* nor *Test Trial Position* produced significant effects and were thus excluded from the main analysis.

Location of First Look

The dependent variable of *correct* looks—that is, first looks categorised as to *target*—was used to analyse first looks and the second measure of *any look to target (within 4 seconds)*.

Table 4.2 shows the results of the main analyses for *correct* first looks and *any look to target (within 4 seconds)*. The first factor included in the models was the main effect of *Trial*. The main focus of interest were the factors of *Age* and *Landmark*, and their interaction.

In the analysis of *correct* first looks, there was no significant main effect of *Trial*, while the main effects of *Age* and *Landmark* were both significant. There were no significant interactions. The *Infant* factor was significant, showing consistency of response between test trials. From Table 4.1 it can be seen that the percentage of *correct* first looks, on both test trials, was 38% in the beacon condition, and 26% in the no beacon condition in the 8.5-month-old group. In the 6-month-old group, the percentages of these *correct* first looks were 27% and 6% in the beacon and no beacon conditions, respectively. Thus the 8.5-month-old infants, on the whole, made more *correct* first looks than the younger infants, although by a modest amount. Infants in both age groups performed slightly better when the beacon was present.
However, a closer inspection of Table 4.1 suggests that the improved performance

Table 4.2. Effects and significance tests for *correct* first looks and *any look to target (within 4 s).*

DependentVariable	EffectName	df	Chi-Square	p
Correct First Looks	Trial	1	.338	.561
	Age	1	4.003	.045
	Landmark	1	4.561	.033
	Trial X Age	1	.031	.911
	Trial X Landmark	1	.403	.526
	Age X Landmark	1	1.167	.280
	Trial X Age X Landmark	1	.022	.882
	Infant	60	90.8	.006
	Residual	42	19.0	.345
Any Look to Target (within 4 s).	Trial	1	.288	.456
	Age	1	3.23	.083
	Landmark	1	3.87	.098
	Trial X Age	1	.058	1.21
	Trial X Landmark	1	.608	.621
	Age X Landmark	1	2.13	.324
	Trial X Age X Landmark	1	.034	.987
	Infant	60	92.9	.004
	Residual	46	24.3	.463

found in the 6-month-old beacon group, should be interpreted with some degree of caution. This caution is necessary because the number of first looks categorised as *undershoot* in the no beacon condition is similar to the number of first looks categorised as *target* in the beacon condition for infants at this age. An interpretation of this finding is that, with the training regime employed—in which infants are exposed to the target both to their left and right—the baseline probability of infants looking in the direction of the event site is higher. In the beacon condition, a look in this direction is more likely to be converted into a look that reaches as far as that categorised as *target*; this would be because either the beacon itself captures attention, or the infant makes a link between the "peek-a-boo" event and the beacon. This pattern of more first looks categorised as *undershoot* in the no beacon condition was not found in the 8.5-month-old group; this explanation for the higher number of *correct* first looks in the presence of the beacon does not apply to this group of older infants.

Any Look to Target (within 4 seconds).

In the analysis of *any look to target (within 4 seconds)*, the only significant main effect was that of *Infant*, again confirming a level of consistency of response between test trials. The level of performance in all four groups is very similar, but the 8.5-month-old beacon group show the highest number of first looks to the event site (*correct* first looks)—47% compared to 30% in the no beacon group. In the 6-month-old beacon group, 35% of infants made a *correct* look within 4 seconds compared to 29% in the no beacon group.

Latency of First Look

The latency to make a first look was analysed using a 2 x 2 x 2 ANOVA (*Age* and *Landmark* were between subject factors, and *Trial* was a repeated measures factor). There were no significant differences between the four groups. The mean latencies ranged from 0.51 (SD = 0.37) seconds to 1.04 (SD = 0.94) seconds.

Discussion

Contrary to predictions, infants in both the 6- and 8.5-month-old groups performed poorly in the beacon and no beacon conditions. There was a slight improvement in task performance at both ages in the measure of *correct* first looks in the beacon condition. However, the interpretation of this effect for the 6-month-old infants is problematic: The beacon could simply have converted what were otherwise first looks categorised as *undershoot* to *target* (and thus *correct*). It appears that for these younger infants, *correct* first looks could be the result of seeing part of the beacon (due to its hoop-like shape) at the *undershoot* location, thus prompting them to extend the direction of their first look.

Despite the similarity in training regime between the present study and that of Tyler and McKenzie (1990), the levels of performance were much lower. At 6 months, Tyler and McKenzie (Study 1) report 60% of the infants making *correct* first looks, with most of the remaining being *undershoots*. At 8 months, they report 90% *correct* first looks (Study 3). This contrasts with 6% and 26% *correct* first looks found in the no beacon condition at 6 and 8.5 months respectively in this study (29% and 30% if *any look to target—within 4 seconds*—is considered). These findings suggest that the use of a rotation only movement and training infants from both sides of the event site prior to testing, does not substantially improve task performance.

The procedural modifications carried out in the present study fail to explain why Tyler and McKenzie (1990) obtained levels of performance higher than Lew et al. (2000) and Crowther et al. (Study 1, 2000). The following study in Chapter 5 is a full methodological replication of Tyler and McKenzie's study.

SPATIAL ORIENTATION ABILITIES IN 8.5-MONTH-OLD INFANTS: A REPLICATION OF TYLER AND MCKENZIE (1990)

The possibility that seemingly minor procedural differences between Study 2 and Tyler and McKenzie (1990) might be responsible for the differences in the results is explored by carrying out a replication of their Study 3 (8 months; non-landmarked condition).

One of these procedural differences is that Tyler and McKenzie (1990) used a flashing light directly ahead of the infant in training and test positions, both to signal the oncoming "peek-a-boo" event and to centre the infant's gaze prior to his or her response. This gaze centering procedure could be important for two reasons. First, the direction of first look is measured from the first *change* in gaze; therefore it is not possible to categorise first looks as *ahead* using this method (as the infant is already fixating ahead). Several infants did make a first look categorised as *ahead* in Study 2, despite not experiencing "peek-a-boo" from this direction in training. These *incorrect* first looks (i.e., those categorised as *ahead*) are not possible with the Tyler and McKenzie procedure. Second, it is possible that gaze centring simplifies the task by reducing response options to either left or right head turns. There are several more options when gaze is not centred; for example, the infant might be looking downwards as well as ahead or to one side prior to the "peek-a-boo" event (e.g., to the right). A first look would therefore involve a look upwards as well as to one side (e.g., to the left).

Another procedural difference between the previous study (Study 2) and those of Tyler and McKenzie (1990) is in the number of training positions used. Tyler and McKenzie used three training positions (e.g., 90° left, 45° right, and 45° left) with a block of two training trials at each position prior to one test trial (e.g., 90° right). The previous study (Study 2) used only two training positions with three training trials at each position in pseudorandom sequence prior to the third, test position. This present study will follow the exact procedure used by Tyler and McKenzie (1990).

A final point of difference between the methodologies used between Study 2 and Tyler and McKenzie (1990) is in the measurement for the location of first look. No time window was specified by Tyler and McKenzie as to when a first look had to be made on the test trial (compared to the 2 s or 4 s time window used in Study 2). No time window is used in the present study. It is also noted that, unlike the laboratory set up used in the present series of studies, Tyler and McKenzie did not have a camera directly ahead of the infant at the test position: The camera was at the location of the event site; 90° to the infant's direction of facing. To ensure maximum possible accuracy in detecting changes of visual fixation, the existing camera arrangement is maintained in the present study.

This study aims to establish whether it is possible to replicate the same level of high performance reported by Tyler and McKenzie (1990) under these conditions. Only a group of 8.5-month-old infants is tested, in an environment with no distinctive landmarks (a non-landmarked condition).

Method

Participants

Participants were recruited using the same methods as those in Study 1. To be included in the sample infants were required to pass the same specified criteria as for Study 1 (see Study 1 for details).[7]

The sample contained 12 infants aged 8.5 months (*M* = 35 weeks, 6 days; *SD* = 1 week, 5 days) and comprised five males and seven females. One further infant was tested but excluded because of a procedural error.

Apparatus

The apparatus was the same as that of Study 1 (for details, see Study 1). This study included the use of eight red Light Emitting Diodes (LEDs) situated at equal intervals around the walls of the enclosure. Eight LEDs (each 1 cm in diameter) were placed 2 cm above the appropriate camera hole (see Figure 5.1). Each LED flashed on and off at a rate of 2.6 pulses per second.

Design

The study replicated the methodology used by Tyler and McKenzie (1990). There were six training trials from three positions (two training trials from each position; see Figure 5.1 for details). Infants tested 90^0 right were trained from positions that faced 90^0 left, 45^0 left, and 45^0 right; and infants tested 90^0 left were trained from positions that faced 90^0 right, 45^0 right, and 45^0 left.

No auditory cue was used. A red LED flashed to cue the appearance of the experimenter. Four of the eight LEDs corresponded to the four directions the infant faced (for the three training positions and the test position) and was operated by the

[7] The spatial task used in the present study (which uses the procedure outlined by Tyler & McKenzie, Study 3, 1990) had only one test trial and no designated time period for responding; thus infants were excluded if they made no response.

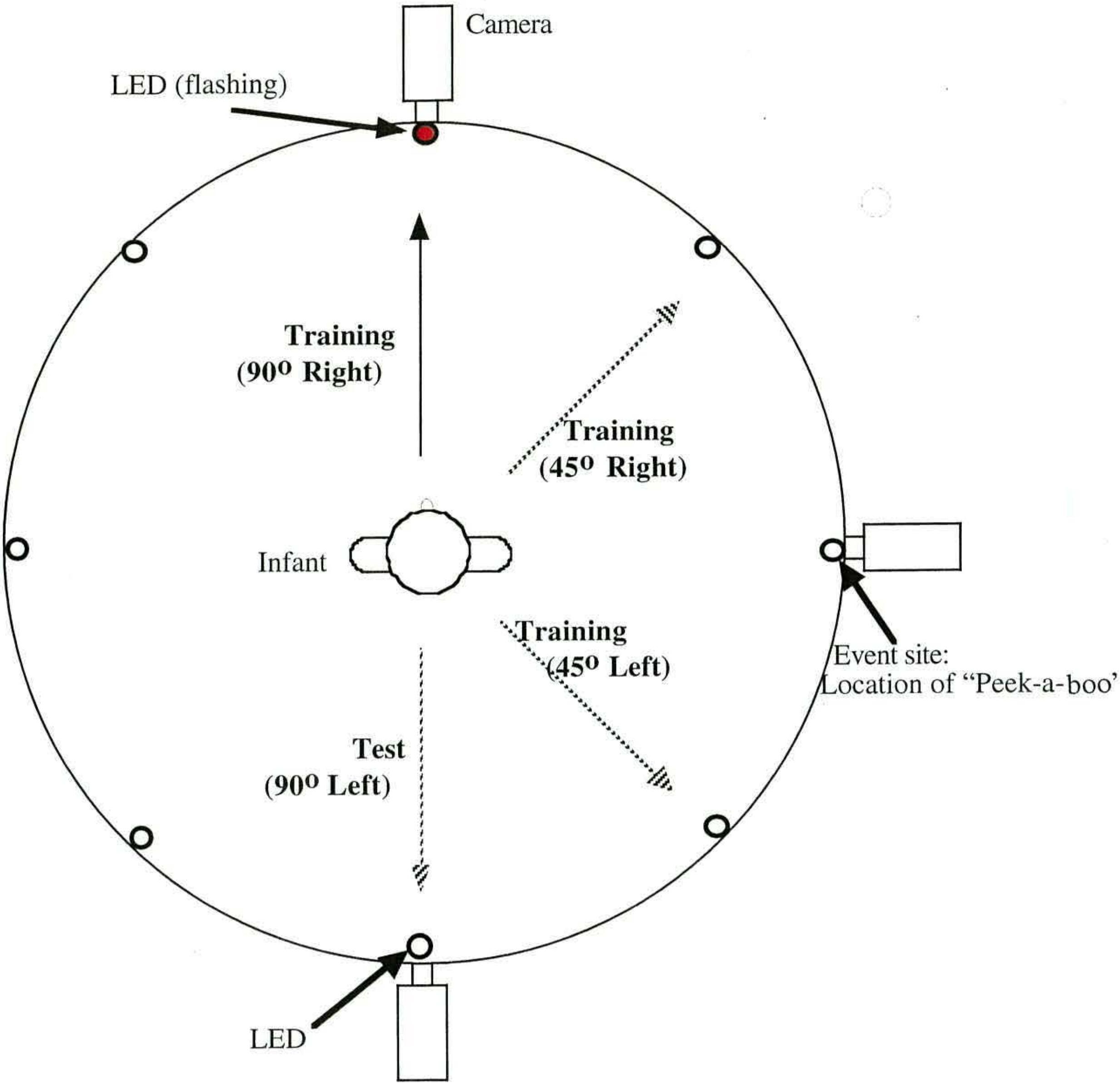

Figure 5.1. The experimental enclosure with the infant facing the direction of the 1st training position. Also depicted are the directions of facing for the 2nd and 3rd training positions, as well as the test position.

experimenter using a remote control. At the beginning of each trial, the flashing LED gained the infant's attention; the infant fixated directly ahead. On training trials, the experimenter appeared after the infant had fixated to the light for a few seconds. Only one light flashed on each trial—the one situated directly ahead of the infant.

After the training trials, one test trial followed. The experimenter did not appear once the flashing light was switched off.

Procedure

The following procedure describes the sequence of positions depicted in Figure 5.1. Infants sat in the baby-seat at the centre of the enclosure.

At the first training position (90° right) the LED situated ahead of the infant started to flash. When the infant fixated to the flashing LED, the LED was switched off and the experimenter appeared through the slit in the curtains (the "peek-a-boo" phase). Training Trial 2 took place from the same position.

After Training Trial 2, the parent rotated the infant to the second training position (45° left) for Training Trials 3 and 4. After Training Trial 4, the parent rotated the infant to the third training position (45° right) for Training Trials 5 and 6.

After Training Trial 6, the parent rotated the infant to the test position, that is, 90° to the left of the event site. From this position one test trial followed. The experimenter did not appear when the flashing LED was switched off.

Inter-Trial Intervals

The procedure contained six inter-trial intervals (five in between the six training trials and one before the test trial). The inter-trial intervals were calculated by measuring the length of time (in seconds) from the end of the "peek-a-boo" phase (when the curtains closed) on the previous training trial to the start of fixation to the visual cue on the next trial. The inter-trial intervals ranged from Mean 5.93 ($SD = 2.02$) seconds to 8.4 ($SD = 6.13$) seconds.

Behavioural Scoring

The direction and latency the infant's first look was scored using the same methods as those in Study 1. However, these methods were modified to suit procedural differences between the present study and Study 1: The *ahead* category for location of first look was removed—as the infant was already fixating ahead (at the flashing LED) at the start of the test trial—and latency of the first look was defined as the time taken (in seconds) from fixating to the flashing LED to the beginning of the change in visual fixation.

Inter-Observer Agreement

A second observer analysed the data from all twelve infants. There was independent agreement on location of first look in all the test trials. The Mean difference in the latency of first look was 0.03 seconds (1 frame) (SD = 0.75 s; 19 frames).

Results

Location of First Look

Five out of the 12 infants (40%) made first looks categorised as *target*. The remaining seven infants made first looks categorised as *opposite*. This level of performance was compared to that reported by Tyler and McKenzie (1990; Study 3, 8 months, associative training condition)—in which 11 out of 12 infants made first looks categorised as *target* (the remaining infant made a first look categorised as *opposite*)—using Fisher's Exact Test (2-tailed). There was a significant difference ($p = 0.03$) between the two levels of performance. The Mean latency of first look was 4.7, (SD = 3.0) seconds.

Location of Longest Look

To examine whether the analysis of location of first look was an accurate measure for the level of performance, a second measure was also used. Instead of using the measure *any look to target (within 4 seconds)*—as used in Studies 1 and 2 of this thesis—the measure of *location of longest look* was used. *Location of longest look* was defined as the location to which the infant looked longest within a 5 second period (starting from the beginning of the first look). Bremner and Hatton (1996), who used the same method of cuing as in this study, also analysed *location of longest look* as a second measure of performance. The 5 second period was measured from the start of the first look.

Analysis of *location of longest look* revealed an almost identical level of performance to that of first look; six infants made longest looks categorised as *target*, and six infants made longest looks categorised as *opposite*. The Mean duration of longest look was 3.73 (SD = 1.26) seconds.[8]

For 11 out of the 12 infants, the *location of longest look* was also the location of their first look (and the location of the remaining infant's longest look was his second look; this location was categorised as *target* and lasted 3 s); this confirms that the two measures—*correct* first look and *location of longest look*—produced almost identical levels of performance to one another.

[8] The duration of longest look for five infants, whose first looks continued for longer than the 5 s period (four of whom made longest looks categorised as *opposite*, and 1 of whom made a longest look categorised as *target*) were recorded as 5 s.

Discussion

From the findings of the present study, it is possible to deduce that the relatively low levels of performance found in Studies 1 and 2 of this thesis are not due to the procedural differences between them and the relevant studies of Tyler and McKenzie (1990). Rather, it was not possible to replicate the same level of high performance reported by them. The results of the present study are more similar to those reported by Bremner and Hatton (1996). This preliminary report by Bremner and Hatton was unable to find such a high level of performance as those by Tyler and McKenzie (1990) under task conditions similar to their study. Bremner and Hatton report that 55.5% of the infants (10 out of 18) made *correct* first looks (and that six out of the remaining infants made first looks categorised as *opposite*). Bremner and Hatton carried out a procedure similar to Tyler and McKenzie except that eight training trials from two directions of facing were used in alternation prior to test trials. The ceiling effect regarding the level of performance at 8 months reported by Tyler and McKenzie may reflect an unusual sample.

It is also possible that the restricted view of the infant's face provided by a camera at a 90° angle from the face led to some *incorrect* first looks (i.e., those away from the location of the event site) being missed by Tyler and McKenzie (1990). Therefore, the *correct* first looks may not have been first looks; the *incorrect* first looks may have been missed. Both Bremner and Hatton (1996) and the present series of sudies had cameras positioned directly facing infants.

The level of performance, although not as high as that reported by Tyler and McKenzie (1990), are higher than those from the previous two studies: 40% versus 19% and 32% for Studies 1 and 2, respectively. This rise in performance is likely to be due to the cuing technique used, that is, the removal of the *ahead* category for location of first look, and making the task simpler by reducing the response options available.

A LONGITUDINAL STUDY EXAMINING THE RELATION BETWEEN SPATIAL ORIENTATION ABILITIES AND CRAWLING

Study 3's failure to replicate the findings reported by Tyler and McKenzie (1990) leaves open the possibility that infants younger than 8 or 9 months are not able to use an allocentric coding strategy.

The findings from the previous studies in this thesis confirm those from other research (e.g., Acredolo & Evans, 1980; Bremner, 1978b; Lew et al., 2000). The findings from these previous studies leave open the possibility that crawling may be a causal factor driving the emergence of the ability to use allocentric coding (landmark use). The onset of crawling as a main factor associated with development in infants' spatial abilities is proposed by several researchers (Acredolo, 1978 & 1985; Bremner, 1985; Bremner & Bryant, 1977—and, more recently, Campos, Anderson, Barbu-Roth, Hubbard, Hertenstein, & Witherington, 2000). This proposal is referred to as the *crawling hypothesis*. The main argument behind this hypothesis is that crawling provides infants with opportunities for attending to the relations between locations and landmarks (i.e., visual features in the environment). The types of methodologies used in the few studies examining this hypothesis have involved various designs; these include deprivation studies, enrichment studies, case studies, and cross-sectional studies. Findings from these studies are inconclusive regarding the influence of crawling on infants' abilities to use an allocentric spatial coding strategy. At present, little evidence exists to substantiate the crawling hypothesis.

Some researchers present alternative explanations for the development of spatial abilities (e.g., Nadel, 1990; Newcombe & Huttenlocher, 2000; Thelen, 2000).

The previous studies in this thesis concentrated on establishing whether infants younger than 8 or 9 months (the average age for the onset of crawling) are able to use an allocentric spatial coding strategy; they concentrated on determining whether the crawling hypothesis is supported. This study attempts to establish the accuracy of the crawling hypothesis. The present study uses a longitudinal design; this design has not previously been used to examine the influence of crawling on spatial ability. The use of this method is preferred because it distinguishes more clearly between both the crawling and the spatial abilities of each infant. Individual differences are less salient in previous cross-sectional studies; this is because such studies only examine infants once and at a specific age.

If the crawling hypothesis is accurate, then the present longitudinal study should show a relation between the age at which an infant is able to use allocentric coding and the age at which he or she begins to crawl. However, evidence demonstrating the existence of a relation between these two ages cannot provide confirmation regarding causality (i.e., the causal influence provided by crawling). It would only be possible to deduce that the two ages are associated. However, it would be possible to deduce that the crawling is not a causal factor if no relation is found to exist between them.

This study also records the age at which each infant begins to sit independently. As well as the ages for the onset of these two developmental milestones (i.e., crawling and sitting) other aspects of individual development are measured: These aspects include the development of cognitive, language, and motor abilities (using the Bayley Scale of Infant Development, 2nd edition; 1993). The inclusion of these measurements should produce a picture of aspects in infant development that may be related to the development of spatial ability. This is important if no association is found with crawling.

To capture the possible influence of crawling, the present study follows infants from an age before to an age after the onset of crawling. The average age for the onset of crawling is between 8 and 9 months. This study therefore follows infants from a few months before to a few months after this age—from 5 to 11 months; this age range captures the onset of crawling in infants who are either earlier or later than average.

Studies 1 and 2 of this thesis show that the use of a simpler movement and training both sides of the event site in the presence of an extra salient beacon does not improve the level of task performance in 6- and 8.5-month-old infants; therefore the methodological procedure of the present study uses the design employed by Lew et al. (2000): It includes the use of a rotation and translation movement (reflecting the type of general trajectory experienced by crawling infants), the ahead training position (considered more rigorous in terms of test trial response novelty; infants are not trained from both sides of the event site), and—in the landmarked condition—two visual features indirectly marking the event site (i.e., with each landmark placed either side).

The previous study (Study 3)—replicating the exact procedure used by Tyler and McKenzie (1990)—found that the use of the visual cuing technique produced clearer behavioural response data than the auditory cuing technique used in Studies 1 and 2. This study includes the use of the same visual cuing technique: A flashing light—to which the infant is required to fixate on prior to the onset of each trial. The present study adopts the same pseudorandom sequencing of trial positions as that used in Study 2; it includes two training trials more than Lew et al.'s (2000) study.

The present study examines the performance of a group of infants over a period of development in both the non-landmarked and landmarked conditions of the spatial orientation task, also recording the age at which they begin crawling. It is predicted that, if the crawling hypothesis is accurate—that is, if crawling is a causal factor determining the emergence of the allocentric spatial coding ability—then the age at which infants begin to show landmark use will be significantly related to the age at which they begin to crawl.

Method

Participants

Volunteers were recruited from antenatal classes held at the local health clinic. The sample comprised 28 infants (12 males and 16 females). Two further infants were recruited but were excluded: One withdrew, and another did not yield a sufficient amount of data—he made *no fixation* on both test trials on four out of the five visits (see below for definition of exclusion criteria). Two infants in the sample were a pair of non-identical (dizygotic) twins. The twins were born nine weeks premature (31 weeks gestational age) and were age corrected to match their due date: They were nine weeks older than the start age when they began the study. The rest of the sample were born between 37 and 43 weeks gestational age.

Data that fell into one of three categories were excluded from analysis: *upset* (the infant became upset during the procedure), *experimenter error* (the experimenter made an error—also included in this category was data deemed void due to external noise), and *no fixation* (the infant did not attend to the visual cue).

For a breakdown of the average age (and standard deviation) of infants, the number of missed visits, and the amount of excluded data for each group at each visit see Table 6.1. There was no significant difference in age between the two conditions with regard to the Spatial Orientation Task. However, for the BSID-II scale, there was a significant difference at the 11-month visit (t (24) = -2.47, p = .02). This significant difference in age at 11-months can be explained by the delay in visits caused by a national fuel crisis. Even though there was this significant difference between the two conditions at this age, it did not result in a significant difference between the two conditions on the BSID-II scores at 11 months.

Table 6.1. Mean ages (and *SD*) and number of missed visits for each condition on both the spatial task and the BSID-II Scale. Also included is a breakdown of excluded data (the number of trials excluded for each exclusion category) for each condition at each visit.

	BSID-II 5 months	Spatial Task 28 weeks	Spatial Task 32 weeks	BSID-II 8 months	Spatial Task 36 weeks	Spatial Task 40 weeks	Spatial Task 44 weeks	BSID-II 11 months
Mean age (& Standard Deviation) landmarked	5 months, 4 days (1 week, 3 days)	28 weeks (3days)	32 weeks (4days)	8 months, 6 days (1 week, 4 days)	36 weeks, 5 days (5days)	40 weeks, 2 days (6days)	44 weeks, 6 days (1 week, 1 day)	11 months, 4 days (5days)
non- landmarked	5 months, 5 days (1 week, 2 days)	28 weeks 2 days (4days)	32 weeks (4days)	8 months 6 days (1 week, 4 days)	36 weeks 6 days (1 week, 1 day)	40 weeks, 3 days (5days)	44 weeks, 3 days (1 week, 1 day)	11 months (4days)
Missed visits landmarked	0	0	1	1	1	0	1	2
non-landmarked	0	2	0	2	1	0	1	0
				Excluded Data (no. of test trials)				
No Fixation landmarked	-	3	0	-	0	0	0	-
non-landmarked	-	0	1	-	0	2	0	-
Upset landmarked	-	0	1	-	0	0	2	-
non-landmarked	-	0	0	-	2	2	0	-
Experimenter Error landmarked	-	0	0	-	0	2	2	-
non-landmarked	-	4	0	-	0	2	0	-

Design

Individual Development and Spatial Ability

The study followed the development of 28 infants over a six month period (from 5 to 11 months). Infants were tested on a spatial orientation task at four week intervals from 28 to 44 weeks (five sessions in total). The study began with a home visit when infants were 5 months. There were two further home visits when infants were 8 and 11 months. At each home visit, the *Bayley Scales of Infant Development II* (*BSID-II*; 1993) measured levels of general development. See Figure 6.1 for a timeline of the visits.

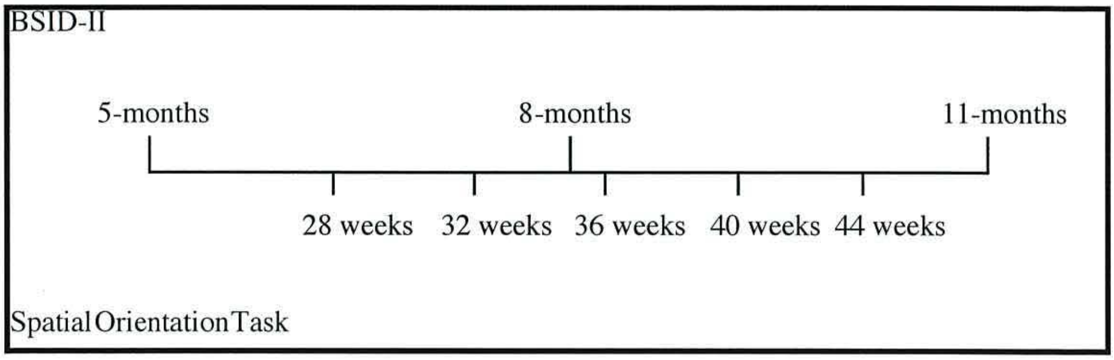

Figure 6.1. Time line of visits showing the age of the infant at each visit.

Individual Development

Bayley scales of infant development II (BSID-II).

The three home visits measured the development of each infant's motor, cognitive, and language abilities. These abilities were measured using the Bayley Scales of Infant Development (1993; 2nd ed.). The BSID-II is an individually administered examination that assesses the current developmental function of infants and children (from 1 month to 42 months). The examination is comprised of three scales: *Mental Scale*, *Motor Scale*, and *Behaviour Rating Scale*.

Each examination required the infant to perform a series of age related tasks (see Appendix A, B, & C for the scoresheets for each scale at the three ages). The infant's performance on the tasks at each home visit was converted into two scores: *Mental Development Index* (MDI) and *Psychomotor Development Index* (PDI).

Other developmental milestones.

During the study (from 5 to 11 months) the onset dates of two milestones in development were also recorded: These were the onset dates for independent sitting and crawling. Before the study began, parents were requested to record the dates of these two milestones. At each visit, parents were asked about their infant's sitting and crawling abilities.

The onset of independent sitting was defined as the ability to sit unaided for at least 30 seconds. The onset of crawling was defined as the ability to move independently over a distance of approximately 2 metres on hands and knees (bellycrawling was not included in this definition).

Spatial Development.

The spatial orientation task.

Participants

Infants were assigned to one of two groups, either the *landmarked* condition or the *non-landmarked* condition. The pair of twins was divided between the two conditions, with one infant in each condition. Each condition contained 14 infants; each condition comprised six males and eight females.

Apparatus

The circular enclosure used was the same as that used in Studies 1, 2, and 3 of this thesis (see Figure 6.2). In the landmarked condition, two coloured lanterns were placed

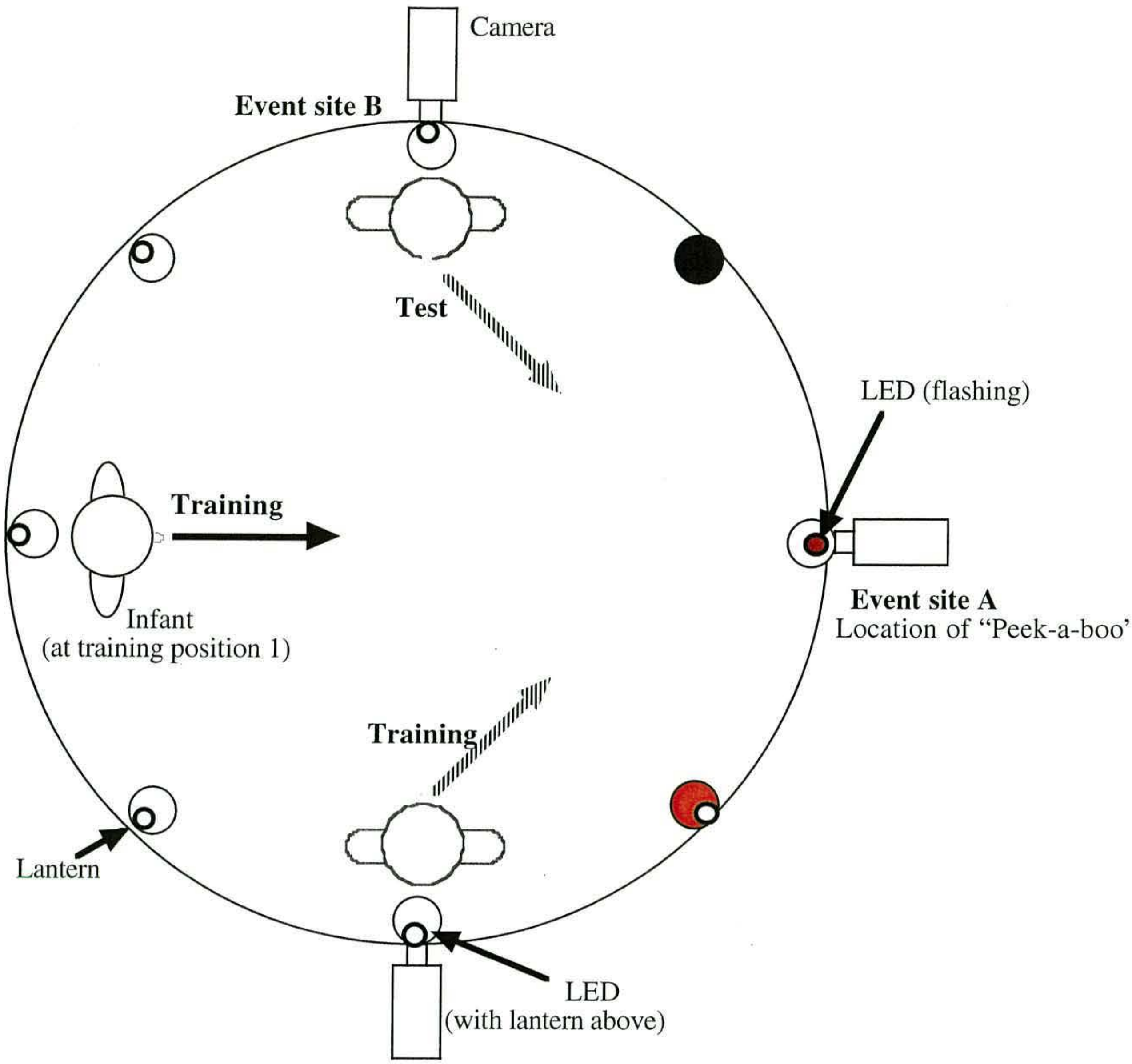

Figure 6.2. The experimental enclosure for the landmarked condition with the infant at the 1st training position. Also depicted are the positions for the 2nd training position and the test position for the event site at Location A. The position of the event site at Location B is also depicted. In the non-landmarked condition, the two coloured lanterns were replaced by lanterns identical to the other six.

either side of the event site (one black and one orange). The black lantern was placed to the left of the event site, and the orange lantern was placed to the right. These lanterns added visual features to the enclosure and landmarked the event site.

The parent sat on a movable chair with the infant sitting on his or her lap.

Design

During six training trials, the infant was trained to associate a visual cue (a red flashing light—an LED) directly ahead, with the appearance of the experimenter at a set location (the event site) from two positions at the perimeter of the enclosure. The infant was moved around the perimeter to the different positions.

After the training trials, the infant was moved to a new position for two test trials in which the experimenter did not appear after the visual cue. The infant's looking response following fixation to the visual cue was recorded and used as an indicator of where he or she expected the experimenter to appear.

Randomisations

Procedural randomisations were used to reduce the influence of practice on spatial task performance over the five visits (at 28, 32, 36, 40, and 44 weeks); these randomisations involved the sequence of training positions, the test trial position, and the location of the event.

Sequence of training positions.

At each visit, the sequence of the two training positions was randomised (each position had three trials); no two visits contained the same sequence of positions.

Test trial position.

The direction to which the infant was required to turn (i.e., either to the left or right) to relocate the event site on test trials was alternated for each visit. Each infant was therefore required to turn in a different direction from that required on the previous visit (e.g., to turn to the left on visits at 28, 36, and 44 weeks, and to the right on visits at 32 and 40 weeks, or vice versa).

Location of event site.

Two locations for the event site were used: *Location A* or *B*. Each infant experienced two visits with the event at Location A and three visits with the event at Location B, or vice versa (see Figure 6.2). The location of the event site for each visit was calculated pseudorandomly.

Procedure

Prior to the procedure, a period of familiarisation (lasting five minutes) took place inside the enclosure. The experimenter talked through the procedure with the parent while the infant played with toys. This period of familiarisation allowed both the parent and the infant to become comfortable with the experimental setting.

The parent sat on the movable chair, with the infant on his or her lap. During the procedure, the parent (still sitting on the chair) wheeled the chair to the required position during training and test trials (these positions were marked discretely on the floor around the perimeter of the enclosure). Before training began, the parent moved on the chair to the centre of the enclosure and rotated the chair several times; this ensured that the infant would not be able to locate the entrance as a result of maintaining fixation on it after the experimenter left. After the rotation, the parent moved to the position required for the first training trial.

The following describes the sequence of positions depicted in Figure 6.2. At the first training position (ahead), Training Trial 1 took place: The experimenter activated the flashing red light situated ahead of the infant; once the infant fixated on the light for a few seconds, the light stopped flashing and the experimenter appeared through the slit in the curtains (the event site) entertaining the infant verbally. The appearance of the experimenter (referred to as the *"peek-a-boo" phase*) lasted 15 seconds. At the end of the "peek-a-boo" phase the experimenter disappeared from view by closing the curtains.

The parent moved round the perimeter of the enclosure to the second training position for Training Trial 2 (with the event site to the infant's right). From the second position the experimenter activated another flashing red light (again situated ahead of the infant). When the infant fixated on the light for a few seconds, the "peek-a-boo" phase followed.

For this sequence of training positions, Training Trials 3 and 4 were back at the first training position (ahead) and Training Trials 5 and 6 were at the second training position (to the right of the event site).

After all six training trials, the parent wheeled the chair to the test position (where, for this particular sequence, the event site was to the infant's left). From this position, two test trials followed: The experimenter activated the flashing red light situated ahead of the infant; when the infant fixated on the light for a few seconds, the light stopped flashing.

On each test trial, the experimenter did not appear when the flashing light was switched off (i.e., there was no "peek-a-boo" phase). The location to which the infant looked first after fixating to the light was recorded. Test Trial 2 ended 5 seconds after the infant made a response.

Inter-Trial Intervals

The procedure contained seven inter-trial intervals (five between the six training trials, and one before and one between the two test trials). The inter-trial intervals during training and the one before Test Trial 1 were calculated by measuring the length of time (in seconds) from the end of the "peek-a-boo" phase (when the curtains closed) on the previous training trial to the start of fixating to the flashing light on the next trial. The inter-trial interval between the two test trials was calculated by measuring the length of time (in seconds) from when the light stopped flashing on Test Trial 1 to the start of fixating to the flashing light on Test Trial 2. This inter-trial interval between the two test trials varied in length depending on the latency of the infant's response. The inter-trial intervals ranged from Mean 14.7 (SD = 3.6) seconds to 16.3 (SD = 2.7) seconds. There was no significant difference between the two conditions regarding the length of the inter-trial intervals.

Behavioural Scoring

The video cameras enabled observational analysis of each infant's behaviour on the test trials. Two measures of behaviour were recorded: The *location* and the *latency* of the infant's first look after fixating on the visual cue (the flashing LED).

An infant's first look was defined as the first change in visual fixation following fixation to the flashing LED (this included anything from a brief change involving eye movement only to a change involving eye and head movement).

Location of first look.

The location of the infant's first look was coded as one of four categories: *target*, *undershoot*, *opposite*, and *other*.

Each code is defined using looking ahead as 0°. Looks in the direction of the event site are referred to using positive degree angles, and looks not in the direction of the event site are referred to using negative degree angles.

Target: between +20° and +70°.

Undershoot: between 0° and +20°.

Opposite: between 0° and -70 °.

Other: visual fixation not defined by the other four codes (i.e., looks that were either down to the floor, at their straps, up at their parent, or up to the ceiling, etc.).

A response was coded as *other* if it was the only response made during the test trial; if the infant made a second response, that response was recorded instead.

An additional category labeled *no response* was used if the infant made no response during the test trial—that is, if he or she continued the same fixation for more than 10 seconds after the light stopped flashing. Visits whereby the infant scored *no response* on both test trials were excluded from the data.

Latency of first look.

The latency of the infant's first look was defined as the time taken (in seconds) from the start of fixating to the flashing light to the beginning of the change in visual fixation.

Inter-Observer Agreement

An inter-observer agreement check was carried out using 40% (97 test trials) of the data set. These test trials were randomly selected within the constraints of having roughly equal numbers of each category of the five response categories (including *no response*). The second coder was blind to which experimental condition was being run. A Cohen's Kappa of agreement on the full set of response categories for location of first look was .87.

Results

Table 6.2 shows the number of infants in each condition (non-landmarked and landmarked) who made first looks to each location category on Test Trials 1 and 2 of the Spatial Orientation Task at each visit (See Appendix D, for Table 9.1 displaying the performance of each infant at each visit).

The Effects of Visit and Condition.

To examine the difference in the level of successful performance between conditions at each visit, the dependent variable of location category of first look was classified as either *correct* or *incorrect*. A first look was classified as *correct* if the location was categorised as *target* or it was classified as *incorrect* if the location was not categorised as *target* (i.e., if the location was categorised as either *undershoot*, *opposite*, or *other*). First looks categorised as *no response* were treated as missing data and were excluded from statistical analysis.

As can be seen from Figure 6.3, apart from the first and the last visit (at 28 and 44 weeks, respectively) there was little difference between the two conditions in the percentage of infants who made *correct* first looks across all the visits. At the oldest age (44 week visit), infants in both conditions showed an improvement in performance relative to the younger ages.

Preliminary analyses focused on checking that there were no systematic differences between the two conditions on sex, location of the event site, and whether the test trial position required a response to either the left or the right. The hierarchical model building approach applied to data analysis was performed using SPSS 10. A binomial distribution of data was assumed and a logit link function was used. Using binary regression analysis, tests of significance were based on log-likelihood ratios and referred to the Chi-square distribution (two-tailed).

Table 6.2. Frequency of First Look to each location category at each visit (age in weeks) and for each condition on Test Trials 1 and 2.

Age	Condition	First Look				n
		Target	Undershoot	Opposite	Other	
		Test Trial 1				
28 wks	non-landmarked	4	0	6	0	10
	landmarked	7	1	5	0	13
32 wks	non-landmarked	3	2	9	0	14
	landmarked	5	1	7	0	13
36 wks	non-landmarked	6	1	5	0	12
	landmarked	6	0	6	1	13
40 wks	non-landmarked	9	0	3	0	12
	landmarked	9	1	3	0	13
44 wks	non-landmarked	9	2	2	0	13
	landmarked	11	1	0	0	12
		Test Trial 2				
28 wks	non-landmarked	2	0	8	0	10
	landmarked	8	1	3	0	12
32 wks	non-landmarked	6	0	7	0	13
	landmarked	7	0	5	0	12
36 wks	non-landmarked	6	1	5	0	12
	landmarked	5	0	7	1	13
40 wks	non-landmarked	7	1	2	0	10
	landmarked	6	2	5	0	13
44 wks	non-landmarked	5	1	6	1	13
	landmarked	8	0	2	0	10

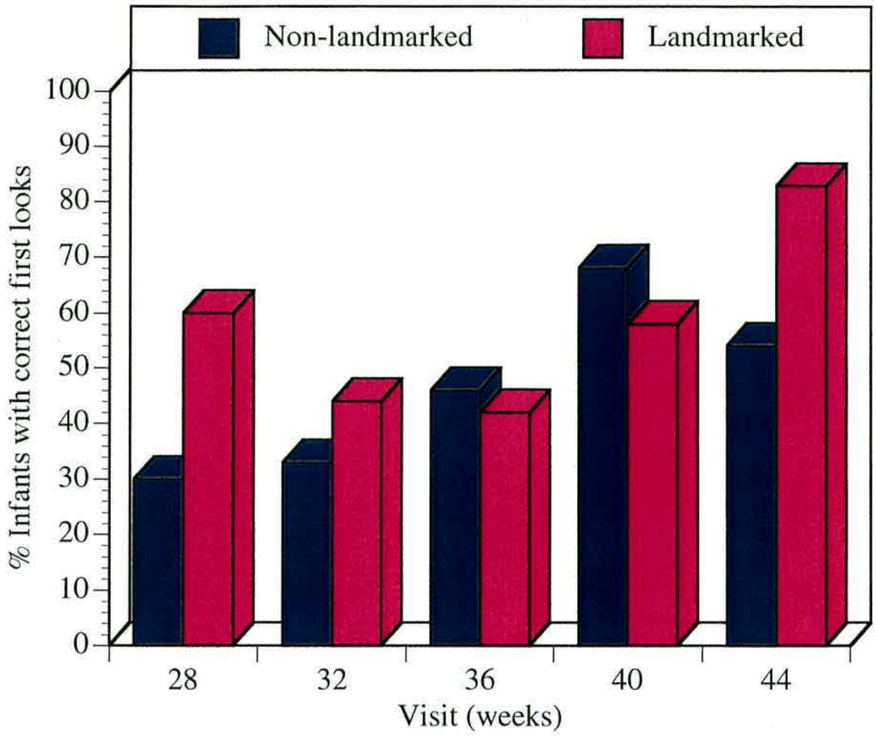

Figure 6.3. Percentage of infants at each visit who made a *correct* first look for each condition (Test Trials 1 & 2 pooled).

The dependent variable was first looks classified as *correct* (i.e., those categorised as *target*). An initial model included the factors of *Trial* (Test Trial 1, Test Trial 2), *Visit* (28-, 32-, 36-, 40-, 44-weeks), *Sex* (Male, Female), *Condition* (Non-Landmarked and Landmarked), *Test Trial Position* (Left, Right), and *Event Location* (Location A, Location B). Table 6.3 shows the results of the analysis for *correct* first looks.

The binary regression analysis found significant main effects for the factors *Test Trial Position*, *Event Location*, and *Visit*.

Post hoc analysis examined the distribution of *correct* first looks as a function of both *Test Trial Position* (Left, Right) and *Event Location* (Location A, Location B). It

Table 6.3. Effects and significance tests on *correct* first looks.

Dependent Variable	Effect name	df	Chi-square	p
Correct first looks				
	Sex	1	.779	.378
	Trial	1	.307	.579
	Test Trial Position	1	6.086	.014
	EventLocation	1	5.121	.024
	Visit	4	12.565	.014
	Condition	1	2.655	.103

became evident that the significant main effects of these factors were due to circumstances in the non-Landmarked condition. A further examination, restricted to this condition, revealed that a combination of variations in the randomisations of these factors and missed visits resulted in two visits containing an uneven distribution of *Event Location.*[9] *Test Trial Position* and *Event Location* were thus excluded from the main analysis. *Sex* was also excluded because it produced no significant effect

Table 6.4 shows the results of the analyses of *correct* first looks. The analysis included the factors of *Trial*, *Visit*, *Condition*, and their interactions. The first factor included in the model was the main effect of *Trial*. Including *Trial* first was considered the most conservative approach because the main focus of interest were the factors of *Visit* and *Condition*, and their interaction; removing any effects due to *Trial* prior to considering these factors was preferred.

[9] The number of infants who experienced the event site at *Location B* in the non-Landmarked condition was at its lowest number on the 32 week visit (n = 3) and highest on the 36 week visit (n = 11). Over the five visits, the *Event Location* was randomised and not alternated, whereas the*Test Trial Position* was alternated.

Table 6.4. Effects and significance tests for *correct* first looks.

Dependent Variable	Effect name	df	Chi-square	p
Correct First Looks				
	Trial	1	.31	.579
	Visit	4	13.67	.008
	Condition	1	2.40	.121
	Trial X Visit	4	8.01	.091
	Trial X Condition	1	.09	.770
	Visit X Condition	4	9.90	.042
	Trial X Visit X Condition	4	1.77	.778
	Infant	26	59.27	0.019
	Residual	198	240.77	0.027

In the analysis of *correct* first looks, there were no significant main effects for the factors *Trial* and *Condition*, or for the interactions *Trial* X *Visit*, *Trial* X *Condition*, and *Trial* X *Visit* X *Condition.* There were significant main effects for the factor *Visit* and for the interaction *Visit* X *Condition.* The significant main effect of *Visit* indicates that there was a significant difference in the level of successful performance over the visits. The significant effect of the difference between *Visit* and *Condition* indicates that the presence of visual features had an effect on successful performance at certain visits.

The significant effect for the *Infant* factor indicates that there were stable individual differences in performance. The significant *Residual* effect implies that the factors used in the binary regression model do not provide a complete account of the results, indicating the existence of extraneous factors. This matter, and its implications, are considered in the discussion.

Difference Between Visits

Each condition was analysed separately to determine which visit (or visits) produced the significant main effect of *Visit* and the significant main effect for the interaction *Visit* X *Condition*. The level of successful performance on each visit was compared to that of each of the other visits. A series of McNemar (Change Test) analyses were used. The McNemar is a non-parametric test for repeated measures design. The dependent variable was the number of infants who made *correct* first looks. This dependent variable was analysed for each visit interaction to determine which visits produced significant differences in the number of infants making *correct* first looks. Analyses were carried out on each test trial separately.

There were significant differences between the 32 week and the 40 week visits (p = .03) in the non-landmarked condition, and between the 32 week and the 44 week visits (p = .03) and the 36 week and the 44 week visits (p = .03) in the landmarked condition. All the significant differences occurred on Test Trial 1.

The series of McNemar tests show that there was an effect of *Visit* present in each condition. For infants in the non-landmarked condition there was a significant difference in the level of successful performance between the 32 week and the 40 week visit. For infants in the landmarked condition, there were significant differences in the level of successful performance between both the 32 and 36 week visits and the 44 week visit.

Difference Between Conditions

Chi-square analysis revealed a significant difference between the two conditions in the number of infants who made *correct* first looks at the 28 week visit (χ^2 (1) 4.10, p = .04) and a significant difference at the 44 week visit (χ^2 (1) 6.21, p = .02).

Summary

The post hoc analyses of visit in general shows improved task performance at older than younger ages. Analysis of the difference in task performance between the conditions shows a significant difference at the 28 and 44 week visit. This finding seems divergent from that of previous literature which found a significant difference at 36 weeks. Reasons for the possible cause of this divergence are considered in the discussion.

Individual Development and Spatial Ability

This section of analysis concentrates on examining the relation between individual development (as measured by the BSID-II and the onset of sitting and crawling) and spatial ability. This analysis appears important given the significant *Infant* and *Residual* main effects, indicating that individual differences had an influence on task performance.

Preliminary analyses focused on checking that there were no systematic differences between conditions on BSID-II scores and the age of sitting and crawling onset.

Bayley Scales of Infant Development II (BSID-II)

The *Mental Development Index* (MDI) and the *Psychomotor Development Index* (PDI) scores obtained from the BSID-II were analysed to rule out any differences between the two conditions. The Mean (and *SD*) scores of each index—at each of the three ages, and for each condition—are reported in Table 6.5. A series of independent sample t-tests at each age (5, 8, and 11 months) revealed no significant difference between the two conditions for the two scores. The BSID-II scores were therefore comparable across the two conditions. Further analysis revealed no significant effect of sex on the MDI and PDI scores at each of the three ages.

Age of Sitting and Crawling Onset

The ages at which infants began sitting and crawling were analysed to confirm comparability between the two conditions. The Mean (and *SD*) age for the onset of sitting was 27.58 (2.65) weeks and 28.18 (3.86) weeks for the non-landmarked and landmarked conditions, respectively. The Mean (and *SD*) age for the onset of crawling

Table 6.5. Mean (and *SD*) scores on Mental scale (MDI) and Psychomotor scale (PDI) for each condition at each home visit.

BSID-II Scale	Home visit		
	5-months	8-months	11-months
		non-Landmarked	
Mental(MDI)	106.29 (5.12)	102.17 (9.52)	98.21 (5.81)
Psychomotor (PDI)	102.93 (8.37)	91 (13.20)	101.64 (13.98)
		Landmarked	
Mental(MDI)	103.36 (5.62)	107.08 (4.09)	97.58 (7.54)
Psychomotor (PDI)	99.5 (6.14)	93.23 (6.48)	96.92 (10.71)

was 36.60 (7.2) weeks and 38.32 (6.39) weeks for the non-landmarked and landmarked conditions, respectively. Two independent sample t-tests revealed no significant differences between the two conditions for the age of sitting onset and the age of crawling onset: The ages for the onset of sitting and crawling were therefore comparable between the two conditions.

Further analysis revealed no significant effect of sex on the age of sitting onset or on the age of crawling onset. Sex as a factor was thus excluded from any main analysis.

Spatial Ability and Crawling Onset

Each infant's performance on the spatial orientation task was analysed to determine the age at which he or she became competent at the task, that is, to determine the onset of task competency. Task competency was characterised by the demonstration of successful performance (that is, a *correct* first look—one categorised as *target*).

However, determining the age for the onset of task competency for each infant was difficult. An examination of each infant's performance on the task over the five visits revealed that levels of successful performance were rarely maintained: There were often regressions in the level of performance (i.e., after demonstrating a level of successful performance, some infants, on occasions, returned to a level of unsuccessful performance). This variability in the level of performance illustrated a high degree of inconsistency in the level of task performance over the visits. This degree of inconsistency was apparent across the full data set. It was therefore important that any criteria used to define the onset of task competency took into account this variability in the level of performance over the visits.

The criteria devised to define the age of onset in task competency stated that (in order for the visit to be classified as demonstrating successful performance) infants were required to produce a *correct* first look, on at least one of the two test trials. To ensure consistency in this level of successful performance, the criteria added that after this successful visit the infant was allowed a maximum of one visit whereby he or she made *incorrect* first looks on both test trials (i.e., a visit demonstrating unsuccessful performance). The visit—at which the infant began to meet this criterion—was used for the age of onset in task competency.

Using this criterion, it was possible to define the onset of task competency for only 14 infants (eight from the non-landmarked condition, and six from the landmarked condition); it was not possible to define the onset of task competency for the remaining 14 infants.

There were unknown ages for the onset of task competency for ten infants, this was because these infants (three from the non-landmarked condition, and seven from the landmarked condition) were competent on the first visit (28 weeks) and maintained their level of successful performance on remaining visits—thus it was not possible to obtain an age for the *onset* of this competency.

It was not possible to define an age of onset in task competency for the remaining four infants; this was due to the requirement for the demonstration of consistency in their level of successful performance: If an infant showed a regression (i.e., a visit whereby the first look on both test trials was *incorrect*) then a subsequent visit was necessary in order for that infant to demonstrate a return to successful performance. Three infants (all from the non-Landmarked condition) were unable to fulfill this requirement of the criterion. These infants regressed on their final visit; thus no subsequent visit was available to enable them to demonstrate a level of consistency in their successful performance. The other infant (from the Landmarked condition) showed successful performance on the last visit only.

However, even with the high degree of inconsistency in the levels of successful performance, it was possible to determine whether each infant was either *Early* or *Late* in achieving task competency. This method for defining the age of onset divided infants into either an *Early* or a *Late* category for achieving task competency. This division thus included every infant; each infant fitted the definition of one of either category. This definition included the 10 infants for whom it was not possible to obtain an age of onset because they were too early in achieving competency; this was because these infants were categorised as *Early*. The four infants who achieved competency too near to the end of the study were categorised as *Late*.

Defining the Early and Late onset of spatial task competency.

To define the age of onset in task competency, infants from each condition were divided into either the *Early* or the *Late* category based upon whether they achieved task competency either early or late.

The *Early* and *Late* categories were defined by calculating the median visit for the onset of competency. The median visit for the onset of task competency was 32 weeks for both the non-landmarked and the landmarked condition.

Defining the Early and Late onset of crawling.

Infants were defined as either *Early* or *Late* crawlers by calculating the median age of crawling onset of infants in each condition. The median age of crawling onset was 35 weeks 6 days in the non-landmarked condition and 38 weeks, 3 days in the landmarked condition. The seven infants from each condition who began crawling before the median age were categorised as *Early* and the seven infants who began crawling after the median age were catgorised as *Late*.

Crawling and spatial competency.

Using the two categories—*Early* and *Late*—for both the onset of crawling and the onset of competency on the spatial task, each infant was divided into one of four groups depending on his or her age of crawling onset and his or her age for achieving task competency. The four groups were (1) *Early Crawling/Early Spatial*, (2) *Early Crawling/Late Spatial*, (3) *Late Crawling/Early Spatial*, and (4) *Late Crawling/Late Spatial*.

The four groups formed a two by two matrix for *Early* and *Late* crawling onset and *Early* and *Late* onset in spatial task competency. Tables 6.6 and 6.7 display the frequency of infants in each of the four groups for the non-landmarked and the landmarked condition, respectively.

If the age of crawling onset and the age of competency onset on the spatial task are related, then the matrix should display a higher frequency of infants in the *Early Crawling/Early Spatial* group compared to the *Early Crawling/Late Spatial* group; and conversely, a higher frequency of infants in the *Late Crawling/Late Spatial* group compared to the *Late Crawling/Early Spatial* group.

Table 6.6. Frequency of infants in the non-landmarked condition categorised as either *Early* or *Late* for both the onset of crawling and the onset of task competency.

		Spatial	
		Early	Late
Crawling	Early	4	3
	Late	4	3

Table 6.7. Frequency of infants in the landmarked condition categorised as either *Early* or *Late* for both the onset of crawling and the onset of task competency.

		Spatial: Early	Spatial: Late
Crawling	Early	4	3
	Late	4	3

As can be seen from both Tables 6.6 and 6.7, the distribution of infants between each of the four groups does not follow the division expected if crawling onset and task competency are related: The distribution of infants between the groups is fairly equal. Fisher's Exact analyses confirmed no significant relation existed between the onset of crawling and task competency (two-tailed; $p = 1.00$) in both conditions.

Spatial competency—before or after crawling onset?

Another analysis examined the distribution of infants who became competent on the task either before or after they began crawling. If the crawling hypothesis is accurate in explaining the development of spatial ability, then this examination of the data should reveal a higher proportion of infants obtaining spatial competency after crawling rather before. Table 6.8 shows the results of this examination for each condition.

Analysis was carried out to examine whether there was a significant difference in the distribution of infants between the two conditions on whether infants gained task competency either before or after they began crawling.

A Fisher's Exact analysis revealed no relation of these two variables between the two conditons (two-tailed; $p = .09$), indicating that gaining task competency was not related to the onset of crawling; this was the same for either condition.

Table 6.8. The frequency of infants in each condition who gained competency on the spatial task either before or after the onset of crawling.

Condition	Before	After
non-Landmarked*	6	6
Landmarked	12	2

* Two infants were excluded because their onsets for spatial competency and crawling were earlier than 28 weeks.

BSID-II Scores and the Onset of Both Spatial Competency and Crawling

The scores obtained from the BSID-II scales and the level of spatial ability were examined to determine whether a relationship existed between these two variables. The scores obtained from the two scales of the BSID-II (the motor and mental scales) may be associated with the onset of spatial ability; higher scores on the BSID-II may be associated with the earlier onset of spatial ability, and conversely, lower scores on the BSID-II may be associated with the later onset of spatial ability.

The scores obtained from each scale were defined as being either *High* or *Low* for each condition by using the same method as that to categorise the onset of spatial ability as either *Early* or *Late*. Infants in each condition were categorised as having either a *High* or *Low* score on each of the two BSID-II scales (motor scale and mental scale) at each of the three ages (5, 8, and 11 months). The *High* and *Low* categories were defined using the median scores: Those infants who scored above the median value were categorised as *High*, and those infants who scored below the median value were categorised as *Low*. Each infant was therefore categorised as either *High* or *Low* on each scale at each age. A two by two matrix was formed for each scale at each of the three ages and for each condition—for example, at 5 months, infants were divided into one of four groups depending on their BSID-II score on the motor scale and their onset of task competency. These four groups were (1) *High Motor/Early Spatial*, (2) *High Motor/Late Spatial*, (3) *Low Motor/Early Spatial*, and (4) *Low Motor/ Late Spatial*. This set of category groups was used for the mental scale, and both sets of groups were repeated for the measures at 8 and 11 months. The median scores were recalculated for each age.

BSID-II scores and the onset of crawling.

The same method was used to examine relation between BSID-II scores and the onset of crawling as that used to examine the relation between BSID-II scores and the onset of spatial competency. Infants were categorised with regard to their *Early* or *Late* onset in crawling.

Due to the low frequency of infants in each group, each matrix was analysed using Fisher's Exact Test. Table 6.9 displays the significance values for each comparison between the *Early* and *Late* onset of each ability (i.e., spatial and crawling) and *High* or *Low* score on each scale of the BSID-II (i.e., the mental scale and the motor scale).

The interaction between scores on the motor scale of the BSID-II at 8 months and spatial ability (in the non-landmarked condition) and between scores on the motor scale of the BSID-II at 5 months and crawling ability (in the landmarked condition) both showed a significant level of association. If the association between 8 month BSID-II motor performance and spatial ability were confirmed by further studies, such an effect would be difficult to interpret as the motor scale involves many items concerned with fine motor control as well as postural control items.

Defining the Early and Late onset of sitting.

Infants were defined as either *Early* or *Late* sitters by calculating the median age of sitting onset of infants in each condition. The median age of sitting onset was 26 weeks, 6 days for the non-landmarked condition and 28 weeks, 5 days for the landmarked condition. The seven infants from each condition who began sitting before the median age were

Table 6.9. Significance values for the relationship between *High* and *Low* scores on the BSID-II scales over age and *Early* and *Late* onset of spatial, crawling, and sitting ability for each condition.

BSID-II		Ability: Spatial	Crawling	Sitting
		Non-Landmarked		
5 month	Motor	.70	.14	.50
	Mental	.53	.70	.30
8 month	Motor	.03 *	.50	.31
	Mental	.42	.73	.15
11 months	Motor	.41	.72	.04 *
	Mental	.70	.50	.50
		Landmarked		
5 month	Motor	.34	.01 *	.13
	Mental	.70	.50	.14
8 month	Motor	.21	.62	.38
	Mental	.62	.21	.38
11 months	Motor	.58	.27	.42
	Mental	.58	.27	.58

* Level of significance <.05

categorised as *Early* and those seven infants who began sitting after the median age were catgorised as *Late*.

Sitting and spatial competency.

Using the two categories—*Early* and *Late*—for the onset of sitting and the onset of competency on the spatial task, each infant was divided into one of four groups depending on his or her age of sitting onset and his or her age of achieving task competency. These four groups were (1) *Early Sitting/Early Spatial*, (2) *Early Sitting/Late Spatial*, (3) *Late Sitting/Early Spatial*, and (4) *Late Sitting/Late Spatial*. The four groups formed a two by two matrix for *Early* and *Late* sitting onset and *Early* and *Late* onset in spatial task competency. Tables 6.10 and 6.11 display the frequency of infants in each of the four groups for the non-landmarked and the landmarked condition, respectively.

Table 6.10. Frequency of infants in the non-landmarked condition categorised as either *Early* or *Late* for both the onset of sitting and the onset of task competency.

		Spatial	
		Early	Late
Sitting	Early	5	2
	Late	3	4

Table 6.11. Frequency of infants in the landmarked condition categorised as either *Early* or *Late* for both the onset of sitting and the onset of task competency.

		Spatial	
		Early	Late
Sitting	Early	6	1
	Late	2	5

If the age of sitting onset and the age of competency onset on the spatial task are linked, then the matrix would display a higher frequency of infants in the *Early Sitting/Early Spatial* group compared to the *Early Sitting/Late Spatial* group; and conversely, a higher frequency of infants in the *Late Sitting/Late Spatial* group compared to the *Late Sitting/Early Spatial* group. Fisher's Exact analyses revealed that the relation between the onset of sitting and task competency was not significant for both conditions; $p = .59$ and $p = .10$ for the non-landmarked and landmarked condition, respectively. However, infants in the landmarked condition are less evenly distributed between the four groups. A one-tailed Fisher's Exact revealed a marginally significant association between the onset of sitting and the onset of competency on the spatial task $p = .051$.

By collapsing the data across both conditions (i.e., by combining the landmarked and non-landmarked conditions), subsequent analysis examined whether a relationship existed between the onset of sitting ability and spatial ability on the task as a whole. This analysis reclassified the *Early* and *Late* groups for the onset of both sitting and spatial ability. However, no significant relation was found ($p = .121$).

BSID-II Scores and the Onset of Sitting

The same method as that used to examine the relation between BSID-II scores and the onset of crawling, was used to examine the relation between BSID-II scores and the onset of sitting. Infants were categorised with regard to their *Early* or *Late* onset in sitting.

Due to the low frequency of infants in each group, each matrix was analysed using Fisher's Exact test. Table 6.9 displays the significance values for each comparison between the *Early* or *Late* onset of sitting and *High* or *Low* scores on each scale of the BSID-II (i.e., the mental scale and the motor scale).

The interaction between 11-month score on the motor scale of the BSID-II and sitting ability (in the non-landmarked condition) showed a significant level of association.

A further interaction was also analysed; the association between crawling ability and sitting ability was non-significant ($p = .50$ and $p = .14$ for the non-landmarked and the landmarked condition, respectively).

Summary

There was no significant relation between the onset of either sitting or crawling and the onset of task competency. Although there was a marginally significant relation for sitting, this applied to the landmarked condition only.

There was little significant association between individual abilities (i.e., language, cognitive, and motor abilities—as measured by the BSID-II; 1993) and the onset of task competency; the only significant association was between scores on the 8 month motor scale and spatial performance in the non-landmarked condition.

Discussion

This study failed to provide significant evidence to support the claim that crawling is a major causal factor driving development in spatial ability. Those infants who began crawling *Early* were not necessarily those who were *Early* at obtaining competency on the spatial task; these infants were equally likely to be *Late* at obtaining competence. This finding does not support the relation expected by the crawling hypothesis. The relation expected by the crawling hypothesis is that those infants who began crawling *Early* would be those who were also *Early* in obtaining competency on the spatial task (and that, conversely, those infants who began crawling *Late* would be those who were also *Late* in obtaining competency on the spatial task).

The non-significant relation between the onset of crawling and the onset of competency on the spatial task was evident in both the non-landmarked and the landmarked condition. Therefore it is possible to conclude that it appears unlikely that crawling is linked to the emergence of either egocentric or allocentric coding (as shown by the level of performance in each condition; the non-landmarked and landmarked condition, respectively).

The lack of significant difference between the levels of performance of infants in the two conditions at 36 weeks (8.5 months) is indicative that the visual features had little influence on task performance at this age. This failure to produce a significant main effect for *Condition* confirms that there was a lack of consistent difference in the performance between the two conditions. The lack of difference in performance between the two conditions is problematic however regarding the main aim of the study, that is, in determining the relation between crawling and allocentric coding (landmark use). Only when performance in a landmarked condition is better than in a non-landmarked condition is it possible to state that infants—in the landmark condition—are using the landmarks (i.e., allocentric coding). Without a significant *Condition* effect, it is difficult to form any firm conclusions about infants' allocentric coding abilities.

Although the study failed to show a significant main effect for *Condition*, it did show a significant interaction between *Condition* and *Visit*. This latter interaction is more applicable to the aim of the study. A significant main effect for *Condition* is not necessary to this study regarding its comparability with previous studies in that the study expected—if the crawling hypothesis is accurate—that no evidence of landmark use would be present until the 36 week visit. It is likely that such pattern of condition effects would have also produce no significant main effect for *Condition*. The pattern of significant *Condition* effects is problematic because of its poor interpretability regarding the emergence of allocentric coding. The pattern of *Condition* effects over the five visits is revealed by the interaction between *Condition* and *Visit* factors.

The significant interaction between *Condition* and *Visit* demonstrates that there was significant difference in the level of performance between the two conditions, but that the effect applied to certain visits only. This significant difference was present at the first (28 week) visit and at the last (44 week) visit. Therefore it appears that infants in the landmarked condition were performing significantly better than those in the non-landmarked condition at 28 and 44 weeks. It is possible to take these findings as evidence of landmark use—allocentric coding—at these ages.

The findings from the present study are divergent from those of previous studies. These previous studies show a significant difference in task performance between a landmarked and a non-landmarked condition in infants at 36 weeks (e.g., Lew et al., 2000; Crowther et al., Study 1, 2000; Study 2 of thesis). Whereas the performance of infants at this age in the present study remained comparable between conditions.

A possible explanation for this divergence in the age reported between the present study and previous ones may concern the cuing technique. The technique used to cue the onset of each trial was different in the present study from that used in some previous studies; those reporting a significant main effect of *Condition* at 36 weeks (e.g., Lew et al., 2000; Crowther et al., 2000, Study 1; Studies 1 and 2 of this thesis). The present study used a flashing light cuing technique.

The use of this type of cuing technique may alter levels of performance; it is possible that this technique reduces the complexity of the task. With this type of cuing method, the *ahead* category for first look is removed—the infant is already fixating ahead at the start of the trial. This may be the case as Study 3 reported levels of performance slightly higher than those in Studies 1 and 2 (both of which did not use the flashing light cuing technique).

A reason for the lack of improvement in performance in the landmarked condition compared to the non-landmarked condition—particularly at 8.5 months (this is the age at which previous studies consistently found a difference)—could be due to the longitudinal aspects of this study's design. The influence of practice effects (whereby performance on the task is influenced by the numerous visits) is possible in studies which examine abilities longitudinally. A cross-sectional study, replicating this study with infants of the same age may cast light on this possibility. If a difference exists between the level of successful performance of infants in the two studies, then it can be said that the longitudinal design has an influence on task performance.

If the longitudinal design of the present study resulted in the lack of significant *Condition* effect at 36 weeks, then a cross-sectional replication study will show lower levels of successful performance compared to the present study; infants in the cross-sectional study do not have the possible benefit of previous visits.

A cross-sectional study replicating the methodology used in the present study would also be able to determine the viability of the explanation outlining the possible influence of the cuing technique: If the cross-sectional study fails to show a significant main effect of *Condition*, then it is more likely that the lack of *Condition* effect at 36 weeks in the present study resulted from the use of the cuing technique. However, it will be difficult to interpret such a result.

The other main finding is that the developmental picture is different from that of previous studies using a cross-sectional design. The present study found that the development of task performance was not a shift-wise progression, that is, once infants became successful, this level of performance did not continue; infants often regressed.

Similar findings have also been found in other longitudinal studies examining the development of certain abilities. Work by Clearfield and Thelen (2001)—examining the development of reaching—found a U-shaped developmental curve when the abilities of infants younger than the proposed age of emergence were examined. Their work showed that these younger infants' abilities were good, then they regressed, then were good again. An earlier longitudinal study by Diamond (1985) did not find such intra-infant divergence in abilities, but did report large individual differences between infants of the same age. It could be that cross-sectional studies miss such important individual patterns in the development of certain abilities.

Related to the issue of individual developmental patterns, this study encountered several problems in defining the performance criteria necessary for defining task competency. The low number of subjects compounded by the occurrence of missed visits, resulted in little data. As a whole, the data illustrated an indiscriminate pattern of performance (this was confirmed by a significant main effect of the *Residual* in the main logit analysis). The indiscriminate nature of the pattern made it difficult to establish a specific definition for the onset of task competency; thus, resulting in the use of a loose definition—that is, either *Early or Late* onset.

An improvement to this study would be to include more infants in each condition. Another way to obtain more data, as well as including more infants, would be to measure task performance at more frequent intervals; this study measured performance at one month intervals. Measuring their performance at two week intervals would provide twice the amount of data, thus, increasing the chance of providing a clearer, more detailed, picture of individual development. However it is important to also consider that this change would increase the likelihood of practice effect influencing performance.

It is possible to conclude that no evidence was obtained from the present study to suggest that a significant relation exists between crawling and the emergence of the ability to use an egocentric spatial coding strategy and possibly between the emergence of the ability to use an allocentric spatial coding strategy also. The uncertainty of this conclusion regarding allocentric coding is due to the indiscriminate pattern of performance found in the landmarked condition. The relation between crawling and the emergence of this coding strategy may become more apparent through the use of the improvements mentioned above.

The age for the onset of successful spatial ability varied between infants: For some infants it was early; for others it was late. This variability indicates that infants at the same age were different in their level of ability, suggesting a need to examine the development of abilities on an individual basis. Studies using a cross-sectional design are not sensitive to showing up such individual differences.

Another finding of the present study is that the onset of sitting appears to be almost significantly associated with spatial ability in the landmarked condition. Infants who began sitting early were more likely to also be those infants who obtained competency on the spatial task early. This effect was present in the landmarked condition only: It was not present in the non-landmarked condition.

If born out by further research, the existence of a relation between the onset of sitting and improved spatial abilities suggests that being able to sit is important for the development of spatial abilities. One reason for its importance could be that infants' level of visual exploration of the environment expands when they begin sitting. Gaining good head control enables infants to scan their surroundings with a greater degree of exploration; this is essential for monitoring spatial relations and forming representations of locations.

This increase in attention to the surroundings may be what is driving the development of spatial abilities, specifically in the emergence of allocentric coding. If this is true, then it appears that increased levels of attention plays a key role. This interpretation is different from that put forward by the crawling hypothesis; it appears that the increase in attention is independent from the onset of crawling, and possibly more related to the onset of sitting.

The main findings from the present study highlight a strong need to examine alternative explanations for the emergence of infants' ability to use an allocentric spatial coding strategy. These alternative explanations, which concentrate on other influences than those related to crawling, could hold the key to uncovering the factor driving this emergence.

GENERAL DISCUSSION

This thesis had two aims; the first was to establish whether infants younger than 8.5 months are able to use an allocentric spatial coding strategy, and the second was to examine whether crawling is linked to the emergence of the ability to use this coding strategy.

Previous research established the age for the emergence of allocentric spatial coding to be at around 9 months (e.g., Acredolo & Evans, 1980; Bremner, 1978b; Lew et al., 2000). These findings leave open the possibility that crawling may be a main causal factor driving the development of infants' spatial abilities; this is referred to as the crawling hypothesis. Evidence of allocentric coding in infants younger than this age has not yet been found. Finding such evidence would weaken support for the crawling hypothesis and produce the need to consider alternative explanations.

The Emergence of Allocentric Coding

The series of cross-sectional studies (i.e., Studies 1, 2, and 3) in this thesis examined the possibility that the performance of younger infants on spatial orientation tasks is influenced by the use of certain methodological procedures. The use of these procedures mask the spatial abilities of infants younger than 8.5 months. In reviewing some of the theories relating to infant development, including those explaining how and why spatial abilities develop, several areas relating to methodological procedures have become apparent.

Type of Movement

The first of these areas concerns the type of movement used to reorientate the infant to the various trial positions during the task. It is proposed that the development of infants' ability to keep track of increasingly complex movements is progressive; hence younger infants have difficulty with complex ones and are more able with simpler ones (e.g., rotation only). The ability to keep track of increasingly complex movements is proposed to be related to development in the infant's motor activity (e.g., Bremner, 1994).

Study 1 examined the possibility that the type of movement used has an influence on task performance. The study replaced the use of a complex movement (involving both rotation and translation) with a simpler one (involving rotation only—without any translation). This study failed to demonstrate a higher level of performance with this simpler movement; this failed to support the idea that infants are not more capable of keeping track of simpler movements than more complex ones. Findings from Study 1 therefore suggest that the use of a simpler movement in Tyler and McKenzie's (1990) study does not explain why their levels of performance are higher than those reported by more recent studies.

Study 1 also found no significant difference in the level of successful performance between 6- and 8.5-month-old infants. The 8.5-month-olds were unable to keep track movements involving rotation only, just as much as movements involving both rotation and translation.

Training Regime and Beacon Saliency

After ruling out the possibility that the higher levels of performance reported by Tyler and McKenzie (1990) were due to the employment of a simpler movement, the influence of other methodological procedures was examined. The second area relating to the procedure concerns the type of training regime used. Because infants in their study were required to make a response during training similar to that required on the test trial, it was believed that this training regime used by Tyler and McKenzie may facilitate the production of *correct* first looks. The training regime used in more recent studies is one that does not produce this possible facilitating effect.

The possibility that this type training regime used could cause higher levels of successful performance is strengthened by evidence from other research findings stating that infants younger than 9 months are not always able to inhibit prepotent responses (Diamond, 1988).

Study 2 also examined infants' ability to use a beacon; it included a beacon condition. The third area relating to the procedure concerns the salience of the beacon. A previous study failed to obtain evidence of beacon use in 6-month-old infants (Crowther et al., Study 1; 2000). This low level of performance at 6 months—in a beacon condition—was explained by suggesting that the beacon was not sufficiently salient for infants at this age. By adopting a more facilitating training regime and using a more salient beacon, Study 2 aimed to increase the likelihood of obtaining evidence of beacon use in these young infants.

Study 2 did not find evidence to support the notion that the high levels of performance reported by Tyler and McKenzie (1990) were due to the type of training regime they employed. It can be concluded that training infants both sides of the event site has only a limited facilitating effect on their task performance. Though performance was low, there was an improvement between 6 and 8.5 months.

The introduction of a more salient beacon did raise the level of performance in the group of 6-month-olds. However, it appears that at this age the increase in the number of *correct* first looks was dependent upon the number of first looks categorised as *undershoot*. Study 2 reported few first looks categorised as *undershoot*. It is possible that the low number of looks in this category was due to infants making first looks initially of an *undershoot* capacity, but upon seeing the beacon—which was large enough so that it was now in the infant's visual field—the look was then extended further towards the event site (as thus a look categorised as *target*—i.e., *correct*). This finding implies that the increase in the number of *correct* first looks in the group of 6-month-olds with this type of beacon may have been less to do with the beacon's increased saliency, and more to do with the fact that because of its shape it served as a visual reminder. This form of response prompting was not possible with the less salient beacon (as used by Crowther et al., Study 1, 2000) as it was too small to be visable at an *undershoot* head turn.

The shape of the beacon used in Study 2 may be a factor that made this type of beacon more salient. In Lew et al.'s (2000) study, coloured lanterns were placed either side of the event site, and were thus in the infant's visual field at an *undershoot* location—as was the hoop-shaped beacon in Study 2—but these had no increase on the level of task performance at 6-months. Therefore it is possible that beacon use at 6 months is not solely reliant on the presence of it in the visual field; if it is, then Lew et al. would have reported a similarly higher level of performance. Beacon use at 6 months could also be reliant on the shape of the beacon; the shape of it has to be different from the other visual features in the environment. It appears that beacon use in 6-month-old infants could be reliant on both the shape of the beacon and its visibility at the time a response is required. This explanation does not apply to the 8.5-month-olds; their level of performance was due to fewer *opposite* first looks compared to the no beacon condition.

Methodological Replication

Study 3 replicated the procedure used by Tyler and McKenzie (1990). The study examined whether the difference between the levels of performance reported by Tyler and McKenzie and those by more recent studies is due to differences in the procedures used. The failure of Study 3 to replicate Tyler and McKenzie's findings confirms that this difference between the studies is not due to methodological matters, but rather that Tyler and McKenzie's conclusions are questionable. The most likely explanation is that the camera set-up used by them to record the behavioural responses led to detecting an inaccurate high level of performance. This explanation adds emphasis to the need to use an accurate measurement; that is, one which detects subtle eye scans, as well as more obvious head turns. The findings also demonstrate that infants are able to relocate locations by eye movement alone; although such movements are subtle, they are a significant indicator of infants' spatial understanding for locating desired locations.

Study 3 also highlighted evidence that behavioural response on the test trial was clearer using the visual fixating cuing technique. This method is different from that used in more recent studies (e.g., Lew et al., 2000; Crowther et al., Study 1, 2000; Studies

1 & 2 of this thesis), all of which used an auditory signal to cue the onset of each trial. The use of a visual cuing technique removes *ahead* as a response category for the direction of first look; infants are already fixating ahead prior to the test trial. The only directions of first look available with this type of cuing technique are either to the left or to the right; the corresponding response categories are either *opposite* or those in the direction of the event site (i.e., *undershoot* and *target*).

With regards to a landmarked condition, the use of this cuing technique—which ensures that infants are fixating ahead—guarantees that the landmarks are present in the periphery of the infant's visual field at the time of cuing. The use of the auditory cuing technique is unable to guarantee this possibility. Having the landmark present in the visual field at the time of cuing may be essential to the use of such visual features (evidence from Study 2 suggests that this may be true, especially for younger infants). When such visual features are not present in the visual field, it is necessary to first locate them.

The lack of improvement in task performance with the use of a rotation only movement compared to one involving both rotation and translation may not be due to the fact that the latter is more difficult but that, because of the infant's location, the visual features (landmarking the event site) are more in the infant's visual field than in rotation only. When positioned in the centre of the enclosure (with the rotation only movement), the same landmark is further on the periphery of the infant's visual field than when he or she is positioned at the perimeter of the enclosure (with the rotation and translation movement).

Another possibility that may influence performance between these two type of movement—that is also unrelated to the degree of complexity of keeping track of either—is the degree of head turn each type requires. With the rotation only movement, a greater degree of head turn is required to locate the event site than with the rotation and translation (90° versus 45°, respectively). This difference in the degree of head turn required may make it easier to produce a more accurate response (i.e., a *correct* first look) when a more complex movement (rotation and translation) is used rather than a simpler movement (rotation only).

A study is needed in order to be able to discriminate between the influence of degree of headturn and type of movement. Such a study would use a rotation only movement (with infants positioned in the centre of the enclosure) but would require the same degree of head turn as that from the rotation and translation movement (e.g., 45°). If performance improves under these task conditions then it would be possible to deduce that the degree of head turn was an important factor in facilitating performance; this may explain why infants previously performed at an equal level with a complex movement as with a simpler movement.

Another study is needed in order to confirm that younger infants may require saliency regarding the shape of landmarks. Such a study would compare performance of 6-month-old infants, in which the event site is landmarked by two distictive landmarks (lanterns) of different shapes (placed either side of the event site), with one in which coloured lanterns (i.e., the same shape as other visual features present but of a different colour) are used. If performance in the different shaped lantern condition is higher then it would indicate that at this age infants were more able to use this type of landmarking. Such a finding would confirm the need of these younger infants to rely on saliency regarding the shape of landmarks.

Summary

The series of cross-sectional studies in this thesis addressed procedural aspects of the spatial orientation task; these were the type of movement, type of training regime, and beacon saliency. By addressing these procedural aspects, it is possible to dismiss claims proposed in the previous literature about the development of this spatial coding strategy; these previous claims highlighted the cause of younger infants' failure to demonstrate allocentric coding (or even beacon use) as resulting from the use of a complex movement, an unfacilitating training, and a lack of landmark saliency. From the findings of these studies, it appears unlikely that infants younger than 8.5 months are able to use landmarks (i.e., allocentric coding) to locate a hidden event in the same way as infants older than 8.5 months. These older infants appear robust in their allocentric coding abilities among different task conditions; these include the type of landmark and movement. The findings therefore support the claims made by previous research that the age for the emergence of this ability is around 8.5 months.

The findings from these three studies also highlight other factors that may be important for younger infants to demonstrate their ability to use allocentric coding; that is, the importance of the visability of landmark (in particular saliency relating to its shape) and the degree of head turn required. It appears that the more visible the landmark (including the distinctiveness of its shape) and the lesser the degree of headturn required, there is perhaps an increased likelihood of obtaining evidence for landmark use (allocentric coding) in 6-month-old infants.

Causal Explanations for the Emergence of Allocentric Coding

The Onset of Crawling

Following the series of cross-sectional studies, the possibility that crawling is a likely causal factor driving the development of spatial abilities—and is particularly linked to the ability to use an allocentric spatial coding strategy—is left open. A further study (Study 4) aimed to examine this possibility directly. The longitudinal design allowed the development of both spatial and motor abilities to be monitored. If the study found a significant relation between the onset of crawling and the onset of competency on the spatial task, then it would provide answers supporting the crawling hypothesis. Although such a finding would secure increased support, it would not guarantee the causal capacity of crawling. However, if the study found no relation between the two abilities then it would argue against the causal nature of crawling.

Study 4 found no significant relation between the onset of crawling and improved spatial ability in either the landmarked or the non-landmarked condition. The early or late onset in crawling did not correspond with the early or late onset in task competency: Infants defined as *Early* crawlers were not necessarily defined as *Early* at achieving task competency; there was an equal possibility that such infants would be defined as *Late*, and vice-versa for those defined as *Late* crawlers. The fact that this lack of relation was found in both the landmarked and the non-landmarked condition implies that the onset of crawling is unlikely to be related to the emergence of either allocentric or egocentric spatial coding strategies, respectively.

However, although the data produced from Study 4 provides strong evidence suggesting this conclusion, it is not possible to be certain about the lack of significant relation regarding allocentric coding. This uncertainty results from the study's failure to obtain significant *Condition* effects at certain visits. Without these significant effects, it is not possible to report that infants in the landmarked condition were using allocentric coding; thus it is difficult to make accurate claims regarding their ability to use this spatial coding strategy. Study 4 did, however, obtain a significant interaction between the factors *Condition* and *Visit*; this is indicative that a significant *Condition* effect existed, but that this effect applied to certain visits only. These effects applied to the 28 week, and the 44 week visits. The significant *Condition* effect at these visits makes it difficult to interpret an emergence of allocentric coding.

Study 4 failed to replicate the findings of previous research regarding 8.5-month-olds' (36-week-olds') ability to use allocentric coding—as shown by a significant effect of *Condition* at this age (i.e., Lew et al., 2000). It appears that Study 4 finds the onset of the ability to use this spatial coding strategy to emerge later in development (i.e., 44 weeks). However, the cause of this divergence in the developmental picture between the two studies is uncertain. A replication of this study with 36-week-old infants (as outlined in Discussion section of the previous chapter) is necessary to provide some certainty regarding the cause of this divergence from previous research findings.

Although Study 4 found no significant relation linking the onset of the ability to use an allocentric coding strategy with the onset of crawling, it did find an almost significant relation linking the onset of task competency in the landmarked condition with the onset of sitting. There were significantly more infants defined as *Early* sitters in the *Early* at achieving spatial competency group than *Late* sitters, and vice-versa for those defined as *Late* sitters.

Visual Attention

If confirmed by further research, this link between sitting ability and the ability to use allocentric coding may provide some degree of support for the claim suggesting the important role visual attention plays in the development of spatial abilities—particularly in the emergence of the ability to use an allocentric coding strategy. The development of allocentric coding may require sufficient levels of visual attention. The onset of sitting ability signifies a time when infants gain a competent level of head control—which in turn allows more visual exploration of the environment. Highlighting the causal role played by visual exploration opposes the role of locomotor exploration—this latter form of exploration is given more justification by the crawling hypothesis. Future work monitoring the development of both infants' visual exploration ability and their performance on spatial orientation tasks is needed in order to establish the viability of a relation between these two abilities.

The failure of Study 4 to provide substantial evidence linking the onset of crawling to the emergence of the ability to use an allocentric spatial coding strategy generates the need to consider factors, other than crawling, that may be driving the development of spatial abilities—in particular the emergence of the allocentric spatial coding strategy.

Brain Maturation

One factor which may require more consideration is the role of brain development. As discussed in Chapter 2, the hippocampus is highlighted as a region of the brain necessary for performing spatial tasks. It is advisable that future work also concentrates on examining the relation linking maturation of this brain region with the development of spatial abilities.

The evidence of the development of allocentric coding in rat pups indicated that the emergence of exploratory behaviours is linked to hippocampal function—which is, in turn, related to the emergence of this particular spatial coding strategy. Analysis of the hippocampal structure in rats shows that this structure possesses a high concentration of neurons referred to as "place" cells (O'Keefe & Nadel, 1978). These cells, situated within the the hippocampus, are activated when the rat is in a particular place in the environment. This level of place dependency regarding their activation is the reason they are labelled "place" cells (O'Keefe, 1979; McNaughton, Barnes, & O'Keefe, 1983).

To provide findings more relevant to human spatial cognition, studies attempting to find the presence of similar functioning neurons in the hippocampal structure of human brains examined non-human primates. Non-human primates are useful because they are similar to humans regarding both the level of behavioural functioning and brain structure. This type of research shows that, rather than possessing "place" cells, non-human primates possess a high concentration of neurons in the hippocampus refered to as "spatial view" cells (Cahusac, Miyashita, & Rolls, 1989a; Rolls, Miyashita, Cahusac, Kesner, Niki, Feigbaum, & Bach, 1989; O'Mara, Rolls, Berthoz, & Kesner, 1994). These are cells which, rather than being activated when the individual is in a particular place in the envirionment, are activated by particular views of the spatial array. This finding instigates the prominent role vision plays in the spatial cognition of non-human primates. This finding, of the presence of "spatial view" cells, also highlights the necessary role visual exploration plays in spatial cognition. The similarity between the brain structure of humans and non-human primates indicates that these findings may also transfer to human spatial functioning.

The recognition of the important role visual exploration plays in spatial cognition also relates to the issue raised in Study 4 regarding the possible link between the onset of sitting ability and the emergence of allocentric coding. The maturation of both the hippocampus and these 'spatial view' cells are perhaps the necessary brain maturation required for the emergence of allocentric spatial coding strategies in humans. Futher research is needed to verify the likelihood of this link.

Summary

The outcome of the longitudinal study (Study 4), examining directly the relation between the onset of crawling and the development of spatial ability, provided little evidence to support the crawling hypothesis. However, it is difficult to rule out the crawling hypothesis as a viable explanation for the development of spatial abilities. This difficultly originates from the findings of the series of cross-sectional studies which highlight several factors that appear necessary to younger infants' use of allocentric coding. Therefore, without addressing the influence of these factors further, it remains possible that infants younger than 8.5 months may be able to use an allocentric coding strategy.

The need to address these factors further is supported by the apparent progress made so far from the original spatial orientation paradigm devised by Acredolo (1978), that is, subsequent studies provided a more accurate picture of infants' spatial abilities through continuing to address performance influencing factors. It is therefore necessary to produce a paradigm that accurately assesses the spatial abilities of younger infants. Evidence to support this necessity comes from the findings of some studies using the visual habituation paradigm. This paradigm reveals competent spatial abilities in young infants which appear to become lost with the use of the "peek-a-boo" paradigm (e.g., Kaufman & Needham, 1999).

Accurately measuring the emergence of the allocentric coding strategy—that is, by using the most appropriate spatial orientation paradigm—holds the key to uncovering the main causal factor driving the development of infants' spatial abilities.

The need to use the appropriate paradigm relates to Newcombe and Huttenlocher's (2000) recent rethinking on the development of spatial abilities. Their ideas advocate the view that the appearance of spatial coding abilities is based upon the situations faced by the infant; that is, the infant learns through the positive and negative feedback he or she receives from the outcome of his or her responses as to which spatial coding strategy is appropriate for that particular situation. Newcombe and Huttenlocher view infants as being born with the ability to use each spatial coding strategy, and that it is not until they gain experience in the appropriate situation relating to each strategy that their ability can be revealed. This view advocates the necessity for adapting the paradigm to best suit the infant's capabilities.

Viewing the process of development as resulting from the interaction of several factors (similar to that held by Newcombe and Huttenlocher, 2000) appears to gain some support from this thesis. This view accepts the role played by both experience (such as that gained from abilities, e.g., crawling, sitting, and visual exploration) and brain maturation (i.e., of areas such as the hippocampus and the parietal cortex) and does not consider each factor to be mutually exclusive.

Considerations for Future Research

In light of the findings from this thesis, several areas requiring further examination are revealed. One of the main areas revealed is that infants younger than 8.5 months may possess the ability to use allocentric coding, but that their ability is limited. The limitations revealed are opposed to those first thought at the beginning of this thesis. It appears from the findings in Studies 1 and 2 that the performance of younger infants on such spatial orientation tasks is limited by the degree of head turn required (as opposed to the type of reorientation movement) and the landmark's distinctive shape coupled with its visibility at the time a response is needed (as opposed to the general saliency of the landmark). It is thus important that future research examines these areas because such research may show evidence of allocentric coding in infants younger than 8.5 months.

Another main area revealed is the potential link between visual exploration and the development spatial abilities. The longitudinal study revealed a marginally significant relation between the onset of sitting and allocentric coding. It is possible that this link may be the result of an increase in visual exploration ability mediated by the onset of independent sitting. This view is given support in light of recent research with non-human primates which emphasises the role of visual processes in spatial cognition. Future research is needed to establish the development of infants' visual exploration abilities. Such research may reveal this ability to be more related to the emergence of allocentric coding than crawling.

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APPENDICES

Appendix A

BSID-II Mental Scale Record Form.

5 months: Item 42 to 66
8 months: Item 59 to 82
11 months: Item 66 to 92

Child's Name ____________________ Child's Gender ________

Caregiver's Name ____________________

Daycare/ School Program ____________________

Place of Testing ____________________

Teacher ____________________

Examiner ____________________

Reason for Referral ____________________

Bayley Scales of Infant Development™ Second Edition

Mental Scale Record Form

	Year	Month	Day
Date of Testing			
Date of Birth			
Chronological Age			
Adjustment for Prematurity			
Corrected Age			

Scale	Factor	Raw Score	MDI	PDI	Confidence Interval (___%)	Percentile	Classification
Mental							
Motor							
Behavior Rating	Attention/ Arousal						
	Orientation/ Engagement						
	Emotional Regulation						
	Motor Quality						
	Additional Items						
	Total Raw Score						

Observations and General Comments ____________________

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Appendix A

Begin 5, 6 & 7 months

End 3 & 4 months

Age Group	Item	Position	Materials	Next Item Scored	Next Item Admin.	Previous Item in Series	Comments/ Scoring Criteria/ Trial & Counted Information	Score C, NC, R RPT, O
	38. Reaches for Suspended Ring	Supine	Ring with String	39		37		
	39. Grasps Suspended Ring	Supine	Ring with String			38		
3 months (End)	**40.** Carries Ring to Mouth		Ring with String			39		
	41. Approaches Mirror Image	Seated	Mirror	49, 50				
5 months (Begin)	**42.** Reaches for Cube	Seated	3 Cubes	44, 45, 53, 57, 58, 65				
	43. Reaches Persistently	Seated	Cube, Rabbit or Other Small Toy					
	44. Uses Eye-Hand Coordination in Reaching	Seated	3 Cubes	45, 53, 57, 58, 65		42		
	45. Picks Up Cube	Seated	3 Cubes	53, 57, 58, 65 (M) 31		44		
	46. Fixates on Disappearance of Ball for 2 Seconds	Supine	Shield & Ball					
	47. (Incidental Observation) Displays Awareness of Novel Surroundings							
	48. Plays with String	Seated	Ring with String	62	62			
6 months (Begin)	**49.** Smiles at Mirror Image	Seated	Mirror	50		41		
	50. Responds Playfully to Mirror Image	Seated	Mirror			49		
	51. Regards Pellet	Seated	Sugar Pellet	(M) 41, (M) 32				
4 months (End)	**52.** Bangs in Play	Seated	Spoon or Other Hard Object					
	53. Reaches for Second Cube	Seated	3 Cubes	57, 58, 65		45		
7 months (Begin)	**54.** (Incidental Observation) Transfers Object from Hand to Hand		Rattle, Ring with String, Spoon, or Other Hard Object					
	55. Lifts Inverted Cup	Seated	Cup; Cube, Rabbit or Other Small Toy	67				
	56. Looks for Fallen Spoon	Seated	Mirror & Spoon					

(circle) Incidental Observation

Number of Items Child Received Credit (C) for This Page: ____

Appendix A

Begin 8, 9, 10 11 & 12 months

End 5, 6 & 7 months

Age Group	Item	Position	Materials	Next Item Scored	Next Item Admin.	Previous Item in Series	Comments/ Scoring Criteria/ Trial & Counted Information	Score C, NC, RF, RPT, O
	57. Picks Up Cube Deftly	Seated	3 Cubes	58, 65, (M) 31, (M) 37		53		
	58. Retains Two Cubes for 3 Seconds	Seated	3 Cubes	65		57		
8 months	**59.** Manipulates Bell, Showing Interest in Detail	Seated	Bell	66				
	60. Attends to Scribbling	Seated	Crayon & Paper					
	61. Vocalizes Three Different Vowel Sounds					22	Vowel Sounds:	
9 months	**62.** Pulls String Adaptively to Secure Ring	Seated	Ring with String	82	82	48		
	63. Imitates Vocalization							
10 months	**64.** Cooperates in Game	Seated	Shield					
	65. Retains Two of Three Cubes for 3 Seconds	Seated	3 Cubes	75		58		
11 months; End 5 months	**66.** Rings Bell Purposely	Seated	Bell			59		
	67. Lifts Cup by Handle	Seated	Cup; Cube, Rabbit, or Other Small Toy			55		
	68. Uses Gesture to Make Wants Known						Gesture(s):	
	69. Looks at Pictures in Book	Seated	Picture Book	73				
	70. Listens Selectively to Two Familiar Words							
12 months	**71.** Repeats Vowel-Consonant Combination					61	Vowel-Consonant Combination(s):	
	72. Looks for Contents of Box	Seated	2 Square Beads & Box (no lid)					
End 6 & 7 months	**73.** Turns Pages of Book	Seated	Picture Book			69		
	74. Puts One Cube in Cup	Seated	Cup & 9 Cubes	86, 95			Number of Cubes in Cup _____	

Circled item number = Incidental Observation

Number of Items Child Received Credit (C) for This Page ______

Appendix A

Begin 3 & 14–16 months

End 8, 9, 10 & 11 months

Age Group	Item	Position	Materials	Next Item Scored	Next Item Admin.	Previous Item in Series	Comments/ Scoring Criteria/ Trial & Counted Information	Score C, NC, RF, RPT, O
	75. Attempts to Secure Three Cubes	Seated	3 Cubes			65		
	76. Jabbers Expressively					71		
	77. Pushes Car	Seated	Car					
13 months	**78.** Vocalizes Four Different Vowel-Consonant Combinations					76	Vowel-Consonant Combination(s):	
	79. Fingers Holes in Pegboard	Seated	Pegboard (no pegs)					
	80. Removes Lid from Box	Seated	Box, Solid Lid, Cube or Other Small Toy			72	**Scoring Criterion:** 2 of 3 Trial 1____ 2____ 3____	
	81. Responds to Spoken Request					70		
3 months	**82.** Suspends Ring by String	Seated	Ring with String			62		
	83. Pats Toy in Imitation	Seated	Squeaky Toy					
	84. Finds One Object	Seated	Rabbit & 2 Cups		96	67	**Scoring Criterion:** 2 of 3 Trial 1____ 2____ 3____	
	85. Removes Pellet from Bottle	Seated	Sugar Pellet & Bottle					
9 months	**86.** Puts Three Cubes in Cup	Seated	Cup & 9 Cubes	95		74	Number of Cubes in Cup _____	
4-16 months 0 months	**87.** Places One Peg Repeatedly 70 seconds	Seated	Pegboard, 6 Yellow Pegs &	98		79	Number of Pegs: Trial 1____ 2____ 3____ Time: Trial 1____ 2____ 3____	
	88. Retrieves Toy (Clear Box I)	Seated	Clear Box, Rabbit or Other Small Toy		105			
	89. Puts Six Beads in Box	Seated	Box, Lid with Hole & 8 Square Beads				**Scoring Criterion:** 6 of 8 Number of Beads ______	
	90. Places One Piece (Blue Board) 150 seconds	Seated	Blue Puzzle Board; 4 Round & 5 Square Pieces (Blue Block Set) &				Number of Pieces _____ Time ______	
	91. Scribbles Spontaneously	Seated	Crayon & Paper		103	60		
1 months	**92.** Closes Round Container	Seated	Round Container					

Incidental Observation

Number of Items Child Received Credit (C) for This Page

Appendix B

BSID-II Motor Scale Record Form.

5 months: Item 25 to 41
8 months: Item 42 to 60
11 months: Item 54 to 69

Bayley Scales of Infant Development Second Edition

Motor Scale Record Form

Child's Name ______________________ Child's Gender ________

Caregiver's Name ______________________

Daycare/ School Program ______________________

Place of Testing ______________________

Teacher ______________________

Examiner ______________________

Reason for Referral ______________________

	Year	Month	Day
Date of Testing			
Date of Birth			
Chronological Age			
Adjustment for Prematurity			
Corrected Age			

Scale	Factor	Raw Score	MDI	PDI	Confidence Interval (____%)	Percentile	Classification
Mental							
Motor							
Behavior Rating	Attention/ Arousal						
	Orientation/ Engagement						
	Emotional Regulation						
	Motor Quality						
	Additional Items						
	Total Raw Score						

Observations and General Comments ______________________

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Appendix B

Begin 4, 5 & 6 months

End 1, 2 & 3 months

Age Group	Item	Position	Materials	Next Item: Scored	Next Item: Admin.	Previous Item in Series	Comments/ Scoring Criteria/ Trial & Counted Information	Score C, NC, RF, RPT, O
4 months	17. Holds Head in Midline Position	Supine						
1 month	18. Elevates Self by Arms	Prone						
	19. Balances Head	Upright				15		
	20. Maintains Head at 45° and Lowers with Control	Prone		24				
2 months	21. Sits with Support	Seated		22, 28, 34				
	22. Sits with Slight Support for 10 Seconds	Seated		28, 34, 36		21		
	23. Keeps Hands Open					6		
	24. Maintains Head at 90° and Lowers with Control	Prone				20		
5 months	25. Shifts Weight on Arms	Prone				18		
	26. Turns from Back to Side	Supine	Bell or Rattle	38		11		
	27. Rotates Wrist		Cube, Rattle, Bell or Other Small Toy					
6 months	28. Sits Alone Momentarily	Seated		34, 36		22		
3 months	29. Uses Whole Hand to Grasp Rod	Seated	Rod				Type of Grasp:	
	30. Reaches Unilaterally		/				Hand ____	
	31. Uses Partial Thumb Opposition to Grasp Cube	Seated	Cube	37				
	32. Attempts to Secure Pellet	Seated	Sugar Pellet	41				

◯ Incidental Observation

Number of Items Child Received Credit (C) for This Page

Appendix B

Begin 7 & 8 months

End 4, 5 & 6 months

Age Group	Item	Position	Materials	Next Item: Scored	Next Item: Admin.	Previous Item in Series	Comments/ Scoring Criteria/ Trial & Counted Information	Score C, NC, RF, RPT, 0
	33. Pulls to Sitting Position	Supine		45				
	34. Sits Alone for 30 Seconds [stopwatch]	Seated	[stopwatch]	36		28		
7 months; 4 months	**35.** Sits Alone While Playing with Toy	Seated	Rabbit, Bell, Rattle or Other Small Toy			34		
	36. Sits Alone Steadily	Seated				35		
	37. Uses Pads of Fingertips to Grasp Cube	Seated	Cube			31		
	38. Turns from Back to Stomach	Supine	Bell or Rattle			26		
	39. Grasps Foot with Hands	Supine	Facial Tissue					
	40. Makes Early Stepping Movements	Standing			44			
5 months	**41.** Uses Whole Hand to Grasp Pellet	Seated	Sugar Pellet	49, 56		32		
8 months	**42.** Attempts to Raise Self to Sit	Supine	Bell or Rattle					
	43. Moves Forward, Using Prewalking Methods	Seated	Bell or Rattle			25		
	44. Supports Weight Momentarily	Standing		46, 53		40		
	45. Pulls to Standing Position	Supine				33		
	46. Shifts Weight While Standing	Standing		53		44		
	47. Raises Self to Sitting Position	Supine	Bell or Rattle			42		
6 months	**48.** Brings Spoons or Cubes to Midline	Seated	2 Spoons or Cubes					

Number of Items Child Received Credit (C) for This Page

Appendix B

Begin 10, 11, 12, 13 & 14–16 months

End 7, 8, 9 & 10 months

Age Group	Item	Position	Materials	Next Item: Scored	Next Item: Admin.	Previous Item in Series	Comments/ Scoring Criteria/ Trial & Counted Information	Score C, NC, RF, RPT, O
9 months	**49.** Uses Partial Thumb Opposition to Grasp Pellet	Seated	Sugar Pellet	56		41		
	50. Rotates Trunk While Sitting Alone	Seated	Bell			36	**Scoring Criterion:** 1 of 2 Trial 1____ 2____	
10 months; (end) months	**51.** Moves from Sitting to Creeping Position	Seated	Bell			50		
	52. Raises Self to Standing Position	Supine	Bell or Rattle			47		
	53. Attempts to Walk	Standing		60, 61		46		
1 months	**54.** Walks Sideways While Holding on to Furniture	Standing				53		
	55. Sits Down (Incidental Observation)	Standing						
	56. Uses Pads of Fingertips to Grasp Pellet	Seated	Sugar Pellet			49		
	57. Uses Partial Thumb Opposition to Grasp Rod	Seated	Rod			29		
2 months	**58.** Grasps Pencil at Farthest End	Seated	Pencil & Paper	70				
	59. Stand Up I	Seated		68		52		
(end) months	**60.** Walks with Help	Standing		61, 62 63		54		
3 months	**61.** Stands Alone	Standing		62, 63		60		
(end) months	**62.** Walks Alone	Standing		63		61	Number of Steps _____	
–16 months	**63.** Walks Alone with Good Coordination	Standing	Any toy that interests child			62	Number of Steps _____	
(end) months	**64.** Throws Ball	Standing	Ball					

◯ Incidental Observation

Number of Items Child Received Credit (C) for This Page [ ]

Appendix B

egin 17-19,)-22, 23-25 & 26-28 months

End 11, 12, 13 & 14-16 months

Age Group	Item	Position	Materials	Next Item Scored	Next Item Admin.	Previous Item in Series	Comments/ Scoring Criteria/ Trial & Counted Information	Score C, NC, RF, RPT, 0
	65. Squats Briefly	Standing				55		
7-19 months	**66.** Walks Up Stairs with Help	Standing	Stairs & any toy that interests child	79	69			
	67. Walks Backward	Standing	Pull Toy			63	Number of Steps ______	
	68. Stands Up II	Standing				59		
1 months	**69.** Walks Down Stairs with Help	Standing	Stairs & any toy that interests child	80		66		
0-22 months	**70.** Grasps Pencil at Middle	Seated	Pencil & Paper	74, 75, 90		58		
	71. Walks Sideways	Standing	Pull Toy			67		
12 months	**72.** Stands on Right Foot with Help	Standing			82			
	73. Stands on Left Foot with Help	Standing			83	72		
	74. Uses Pads of Fingertips to Grasp Pencil	Seated	Pencil & Paper	75, 90		70		
23-25 months	**75.** Uses Hand to Hold Paper in Place	Seated	Pencil & Paper	90				
13 months	**76.** Places 10 Pellets in Bottle in 60 Seconds	Seated	12 Sugar Pellets, Bottle &			56	Number of Pellets ______	
	77. Runs with Coordination	Standing	Ball			71		
26-28 months	**78.** Jumps off Floor (Both Feet)	Standing	Jumping Rope					
14-16 months	**79.** Walks Up Stairs Alone, Placing Both Feet on Each Step	Standing	Stairs & any toy that interests child	95	80	69		
	80. Walks Down Stairs Alone, Placing Both Feet on Each Step	Standing	Stairs & any toy that interests child		81	79		

Incidental Observation

Number of Items Child Received Credit (C) for This Page

Appendix C

BSID-II Behaviour Rating Scale Record Form

Child's Name ______ Child's Gender ____
Caregiver's Name ______
Daycare/ School Program ______
Place of Testing ______
Teacher ______ Examiner ______
Reason for Referral ______

	Year	Month	Day
Date of Testing			
Date of Birth			
Chronological Age			
Adjustment for Prematurity			
Corrected Age			

Bayley Scales of Infant Development™ Second Edition

Behavior Rating Scale Record Form

Factor	Raw Score	Percentile	Classification
Attention/ Arousal			
Orientation/ Engagement			
Emotional Regulation			
Motor Quality			
Additional Items			
Total Raw Score			

Observations and General Comments ______

Rating: 1–5 months, 6–12 months, 13–42 months

Attention/ Arousal Factor

3. Predominant State
4. Lability of State of Arousal
5. Positive Affect
6. Negative Affect
7. Soothability When Upset
9. Energy
11. Interest in Test Materials and Stimuli
13. Exploration of Objects and/or Surroundings
19. Orientation to Examiner

Total Attention/Arousal Factor

Orientation/ Engagement Factor

3. Predominant State
4. Lability of State of Arousal
5. Positive Affect
9. Energy
11. Interest in Test Materials and Stimuli
12. Initiative with Tasks
13. Exploration of Objects and/or Surroundings
15. Persistence in Attempting to Complete Tasks
16. Enthusiasm Toward Tasks
17. Fearfulness
19. Orientation to Examiner
20. Social Engagement

Total Orientation/Engagement Factor

Emotional Regulation Factor

6. Negative Affect
8. Hypersensitivity to Test Materials and Stimuli
10. Adaptation to Change in Test Materials
14. Attention to Tasks
15. Persistence in Attempting to Complete Tasks
18. Frustration with Inability to Complete Tasks
19. Orientation to Examiner (Do not add to Total Raw Score Ages 13–42 months)
21. Cooperation
29. Frenetic Movement
30. Hyperactivity

Total Emotional Regulation Factor

Motor Quality Factor

22. Gross-Motor Movement Required by Tasks
23. Fine-Motor Movement Required by Tasks
24. Control of Movement
25. Hypotonicity
26. Hypertonicity
27. Tremulousness
28. Slow and Delayed Movement
29. Frenetic Movement (Do not add to Total Raw Score Ages 13–42 months)

Total Motor Quality Factor

Additional Items

7. Soothability When Upset
8. Hypersensitivity to Test Materials and Stimuli
10. Adaptation to Change in Test Materials
27. Tremulousness

Total Additional Items

Total Raw Score

1–5 months 6–12 months 13–42 months

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Appendix C

You must obtain the information for Items 1 and 2 from the child's caregiver at the completion of the evaluation.

Item	Rating (Circle)
1. Parental Assessment of Test Session	
Ask the caregiver: "How typical was your child's behavior? Did (child's name) play the way she (or he) usually does? Was she (or he) as happy or upset as usual? As alert and active as usual?"	
Very atypical; caregiver never sees this type of behavior	1
Mostly atypical	2
Somewhat typical; caregiver sees this type of behavior on some occasions	3
Typical	4
Very typical; caregiver always sees this type of behavior	5
2. Parental Assessment of Test Adequacy	
Ask the caregiver: "Do you think (child's name) did as well as she (or he) could? Have you seen (child's name) do better or worse on the type of things we worked on?"	
Poor indicator of child's optimal performance; child always performs much better	1
Barely adequate	2
Adequate; child performs as well, on average	3
Good	4
Excellent; child never performs better	5
3. Predominant State 1–12 months	
Drowsy or asleep	1
Typically drowsy; a few moments of wakefulness	2
Drowsy half the time; awake and alert half the time	3
Typically awake and alert; a few moments of drowsiness	4
Awake and alert	5
4. Lability of State of Arousal 1–12 months	
Constant changes from state of drowsiness or sleeping to alert state	1
Frequent changes of state of drowsiness or sleeping to alert state	2
Several changes of state of drowsiness or sleeping to alert state	3
One or two changes in state of drowsiness or sleeping to alert state	4
Constant state of drowsiness or alertness	5

Appendix C

Item	Rating (Circle)
5. Positive Affect 1–42 months	
No positive affect displayed	1
One or two brief displays of positive affect	2
Three or more brief displays of positive affect	3
One or two intense, heightened, or prolonged displays of positive affect	4
Three or more intense, heightened, or prolonged displays of positive affect	5
6. Negative Affect 1–42 months	
Three or more intense, heightened, or prolonged displays of negative affect	1
One or two intense, heightened, or prolonged displays of negative affect	2
Three or more brief displays of negative affect	3
One or two brief displays of negative affect	4
No negative affect displayed	5
7. Soothability When Upset 1–42 months	
Cannot be soothed	1
Soothed only by being physcially comforted (e.g., held, patted)	2
Soothed by being given a desired toy or object	3
Soothed by being spoken to	4
Does not need external assistance to be soothed	5
8. Hypersensitivity to Test Materials and Stimuli 1–42 months	
Constantly hypersensitive; hypersensitivity disrupts testing	1
Typically hypersensitive; returns to test activity in one or two instances	2
Occasionally hypersensitive	3
Typically reacts appropriately; hypersensitive in a few instances	4
Constantly responds appropriately	5

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Item	Rating (Circle)
9. Energy 1–42 months	
Consistently lacks animation or energy; tired and lackluster	1
Typically tired and lackluster; one or two periods of animation or energy	2
Animated or energetic half the time; tired and lackluster half the time	3
Typically animated or energetic; one or two periods of being tired and lackluster	4
Consistently animated or energetic	5
10. Adaptation to Change in Test Materials 1–42 months	
Consistently resists relinquishing materials and/or refuses to accept new materials	1
Typically resists relinquishing materials and/or refuses to accept new materials; makes one or two transitions easily	2
Makes poor transitions half the time; makes good transitions half the time	3
Typically relinquishes materials and accepts new materials; one or two poor transitions	4
Consistently relinquishes materials and accepts new materials	5
11. Interest in Test Materials and Stimuli 1–42 months	
No interest	1
One or two displays of interest	2
Moderate interest	3
Much interest	4
Constant interest	5
12. Initiative with Tasks 6–42 months	
Consistently shows no initiative	1
Typically shows no initiative; one or two instances of initiative	2
Shows initiative half the time	3
Typically shows initiative; one or two instances of no initiative	4
Consistently shows initiative	5

Appendix C

Item	Rating (Circle)
13. Exploration of Objects and/or Surroundings 1–42 months	
No exploration	1
One or two instances of exploration	2
Moderate exploration	3
Much exploration	4
Constant exploration	5
14. Attention to Tasks 6–42 months	
Constantly off task; does not attend	1
Typically off task; attends in one or two instances	2
Off task half the time	3
Typically attends; attention wanders in one or two instances	4
Constantly attends	5
15. Persistence in Attempting to Complete Tasks 6–42 months	
Consistently lacks persistence	1
Typically not persistent; one or two instances of persistence	2
Lacks persistence half the time	3
Typically persistent; lacks persistence in one or two instances	4
Consistently persistent	5
16. Enthusiasm Toward Tasks 6–42 months	
Consistently unenthusiastic; no particular interest beyond attending to the tasks	1
Typically unenthusiastic; enthusiastic in one or two instances	2
Unenthusiastic half the time	3
Typically enthusiastic; unenthusiastic in one or two instances	4
Consistently enthusiastic	5
17. Fearfulness 6–42 months	
Constantly fearful; never trusting	1
Typically fearful; one or two instances of trust	2
Fearful half the time; trusting half the time	3
Typically trusting; one or two instances of fear	4
Constantly trusting; never fearful	5

Appendix C

Item	Rating (Circle)
18. Frustration with Inability to Complete Tasks 6–42 months	
Consistently becomes frustrated	1
Typically becomes frustrated	2
Occasionally becomes frustrated	3
Rarely becomes frustrated	4
Never becomes frustrated	5
19. Orientation to Examiner 1–42 months	
Consistently avoids or resists; never responsive	1
Typically avoids or resists; one or two instances of responsiveness	2
Avoids or resists half the time; responds half the time	3
Typically responds; one or two instances of avoidance or resistance	4
Consistently responds; never avoidant or resistant	5
20. Social Engagement 6–42 months	
No attempts to interact socially	1
One or two attempts to interact socially	2
Several attempts to interact socially	3
Many attempts to interact socially	4
Constant attempts to interact socially	5
21. Cooperation 6–42 months	
Consistently resists suggestions or requests	1
Typically resists suggestions or requests; one or two instances of cooperation	2
Resists suggestions or requests half the time; cooperates half the time	3
Typically cooperates; one or two instances of resistance	4
Consistently cooperates	5
22. Gross-Motor Movement Required by Tasks 1–42 months	
Consistently inappropriate	1
Typically inappropriate; one or two instances of appropriate gross–motor movement	2
Inappropriate half the time; appropriate half the time	3
Typically appropriate; one or two instances of inappropriate gross–motor movement	4
Consistently appropriate	5

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Item	Rating (Circle)
23. Fine–Motor Movement Required by Tasks 6–42 months	
Consistently inappropriate	1
Typically inappropriate; one or two instances of appropriate fine–motor movement	2
Inappropriate half the time; appropriate half the time	3
Typically appropriate; one or two instances of inappropriate fine–motor movement	4
Consistently appropriate	5
24. Control of Movement 1–42 months	
Consistently jerky or clumsy	1
Typically jerky or clumsy	2
Jerky or clumsy half the time; smooth or coordinated half the time	3
Typically smooth or coordinated	4
Consistently smooth or coordinated	5
25. Hypotonicity 1–42 months	
Consistently hypotonic; like a rag doll	1
Typically hypotonic; one or two instances of normal muscle tone	2
Hypotonic half the time; normal muscle tone half the time	3
Typically normal muscle tone; one or two instances of hypotonicity	4
Absence of hypotonicity	5
26. Hypertonicity 1–42 months	
Consistently hypertonic; muscles are rigid and tight	1
Typically hypertonic; one or two instances of normal muscle tone	2
Hypertonic half the time; normal muscle tone half the time	3
Typically normal muscle tone; one or two instances of hypertonicity	4
Absence of hypertonicity	5
27. Tremulousness 1–42 months	
Constant	1
Frequent	2
Occasional	3
Infrequent	4
None	5

Appendix C

Item	Rating (Circle)
28. Slow and Delayed Movement 1–42 months	
Consistently slow and delayed	1
Typically slow and delayed; one or two instances of movement that has appropriate timing and pacing	2
Slow and delayed half the time; appropriately timed and paced half the time	3
Typically appropriate timing and pacing; one or two instances of slow and delayed movement	4
Consistently appropriate timing and pacing	5
29. Frenetic Movement 1–42 months	
Consistently frenetic	1
Typically frenetic; one or two instances of movement that has appropriate timing and pacing	2
Frenetic half the time; appropriately timed and paced half the time	3
Typically appropriate timing and pacing; one or two instances of frenetic movement	4
Consistently appropriate timing and pacing	5
30. Hyperactivity 6–42 months	
Consistently hyperactive; fidgety and agitated in movement	1
Typically hyperactive; one or two instances of appropriate activity level	2
Hyperactive half the time; appropriate activity level half the time	3
Typically not hyperactive; one or two instances of hyperactivity	4
Consistently not hyperactive; never fidgety or agitated in movement	5

Appendix D

Table 9.1. The performance of each infant on the Spatial Orientation task in the two conditions at each visit.

	Visit									
	28 weeks		32 weeks		36 weeks		40 weeks		44 weeks	
	TestTrial									
Infant	1	2	1	2	1	2	1	2	1	2
non-landmarked										
1.	Opp	Opp	Opp	Opp	**Target**	Opp	Opp	**Target**	-	-
2.	b	b	**Target**	**Target**	a	a	**Target**	**Target**	**Target**	Other
3.	-	-	Opp	**Target**	Under	Under	a	a	**Target**	Opp
4.	**Target**	**Target**	Opp	**Target**	**Target**	**Target**	**Target**	c	**Target**	Opp
5.	**Target**	Opp	Under	**Target**	**Target**	Opp	b	b	**Target**	Under
6.	Opp	Opp	**Target**	**Target**	**Target**	**Target**	Under	**Target**	Under	**Target**
7.	**Target**	**Target**	Under	Opp	**Target**	Under	Opp	**Target**	**Target**	**Target**
8.	Opp	Opp	Opp	Opp	Opp	Opp	**Target**	**Target**	**Target**	Opp
9.	b	b	Opp	**Target**	**Target**	**Target**	Opp	Opp	**Target**	**Target**
10	Opp	Opp	Opp	Opp	Opp	**Target**	**Target**	**Target**	**Target**	**Target**
11.	**Target**	Opp	Opp	Opp	Opp	Opp	**Target**	Under	Opp	Opp
12.	-	-	Opp	Opp	Opp	**Target**	**Target**	Opp	Opp	Opp
13.	Opp	Opp	**Target**	c	-	-	**Target**	c	**Target**	**Target**
14.	Opp	Opp	Opp	Opp	Opp	Opp	**Target**	**Target**	Under	Opp
landmarked										
15.	c	c	Opp	Opp	**Target**	**Target**	b	**Target**	**Target**	Opp
16.	Opp	**Target**	**Target**	**Target**	Opp	Opp	**Target**	Opp	**Target**	Opp
17.	**Target**	**Target**	Under	**Target**	**Target**	**Target**	**Target**	**Target**	**Target**	**Target**
18.	**Target**	**Target**	**Target**	**Target**	**Target**	**Target**	**Target**	b	**Target**	**Target**
19.	Opp	c	Opp	**Target**	**Target**	Opp	**Target**	Opp	a	a
20.	**Target**	**Target**	Opp	**Target**	Other	Other	Under	Under	**Target**	**Target**
21.	Opp	Opp	Opp	Opp	Opp	Opp	**Target**	Opp	Under	**Target**
22.	Opp	Opp	**Target**	**Target**	**Target**	Opp	**Target**	**Target**	-	-
23.	**Target**	Opp	Opp	Opp	-	-	**Target**	**Target**	**Target**	**Target**
24.	Opp	**Target**	**Target**	a	**Target**	Opp	**Target**	**Target**	**Target**	b
25.	**Target**	**Target**	Opp	Opp	Opp	Opp	Opp	**Target**	**Target**	**Target**
26.	**Target**	**Target**	Opp	**Target**	Opp	**Target**	Opp	Opp	**Target**	b
27.	Under	**Target**	-	-	Opp	**Target**	Opp	Opp	**Target**	**Target**
28.	**Target**	Under	Opp	Opp	Opp	Opp	**Target**	Under	**Target**	**Target**

Excluded Data (- = missed visit), a = Upset, b = No Fixation, c = Experimenter Error.