Location Memory in Healthy Preterm and Full-Term Infants

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Current research suggests that preterm birth, in and of itself, can have important consequences for the development of cognitive abilities. The research reported here investigated the development of egocentric location memory, and related attention behaviors, in preterm and full-term infants. In Experiment 1, healthy preterm and full-term infants were tested longitudinally at 2.5, 4.5, and 6.5 months of age on a location memory task. The preterm infants were tested at corrected age (i.e., age since expected due date). In this task, infants saw a toy lion hidden at one of two identical locations, a delay was imposed (5, 10, and 30 s at 2.5, 4.5, and 6.5 months, respectively), and then the lion either reappeared at the correct location (expected test event) or at the incorrect location (unexpected test event). At each age tested, the infants looked significantly longer at the unexpected than expected event, as if they remembered the correct location of hiding and found the reappearance of the lion at the incorrect location surprising. There were no reliable differences between the full-term and preterm infants. Results from a control experiment (Experiment 1A) suggest that the longer looking times to the unexpected event were not due to superficial differences between the two test events. Examination of attention behaviors (i.e., mean length of looks and trial length) during the encoding period also revealed no reliable differences between the preterm and full-term infants. However, looking times to the test events, and mean length of looks during the encoding period, decreased reliably with age. Experiment 2 was conducted to investigate whether the observed changes in attention could be attributed to repeated exposure to the test events or to longer delay intervals. The results of Experiment 2 suggest that the observed changes in attention were not due to either of these factors. Together, the results of Experiments 1 and 2 suggest that (a) even very young infants can represent and remember the location of a hidden object, (b) attention behaviors during the location memory task change reliably with age, and (c) uncomplicated premature birth has no obvious effect on the development of location memory and related attentional abilities during the first 6.5 months corrected age.

infancy   cognition   location memory   preterm infants

Infants' ability to remember the location of hidden objects has long interested researchers in the field of infant cognition. Findings from manual search paradigms reveal that it is not until around 8 months of age that infants begin to search for hidden objects, and even then they often search at the wrong location (Piaget,

1954). Successful search depends largely on the delay interval between hiding and search; the mean delay at which 8-month-old infants can successfully search for a hidden object is 2 s and increases at a mean rate of 2 s per month (Diamond, 1985). Many interpretations have been offered for infants' poor performance on manual search tasks, including a limited understanding of object permanence (Piaget, 1954) and inadequate memory mechanisms (e.g., Harris, 1989; Wellman, Cross, & Bartsch, 1987). However, recent research using violation-of-expectation paradigms, rather than search paradigms, suggests that even very young infants can represent the existence and properties of hidden objects (Baillargeon, 1987, 1991; Spelke, Breinlinger, Macomber, & Jacobson, 1992). Findings such as these have led researchers to suggest that infants' poor performance on search tasks is better explained by limitations in inte-

grating knowledge with action (Baillargeon, DeVos, & Graber, 1989; Diamond, 1985) than by a limited understanding of object permanence or faulty memory. This has left open the possibility that even very young infants are capable of remembering the location of hidden objects but are unable to express this knowledge through a manual response.

To avoid the problems associated with search tasks, Baillargeon et al. (1989) investigated location memory in 8-month-old infants in a violation-of-expectation paradigm. In their experiment, infants saw an object hidden at one of two identical locations. After a delay, the object reappeared either from where it was hidden (expected or possible event) or from the other location (unexpected or impossible event). If infants remember the location of the hidden object, they should expect the object to reappear at the correct location and be surprised when it reappears at the incorrect location. The infants looked significantly longer at the unexpected than expected test event, even after a delay as long as 70 s, as if they remembered the location of the hidden object and found its reappearance at the incorrect location surprising. These results suggest that 8-month-old infants can remember the location of a hidden object after a delay much longer than suggested by performance on manual search tasks. This raises the question as to whether infants younger than 8 months of age can also demonstrate this ability.

Two series of experiments conducted by Baillargeon and colleagues suggest that younger infants are sensitive to location information and can use this information to predict the outcome of physical events. In one series of experiments (Baillargeon, 1986; Baillargeon & DeVos, 1991), infants saw an object (e.g., a toy mouse) placed either in front of, on, or behind a track. Next, the object and the middle portion of the track were occluded by a screen. The infants then saw a toy car roll down the track and emerge from behind the screen. If infants expect objects to continue to exist when hidden, expect moving objects to follow a constant trajectory, and can remember the location of the toy mouse relative to the track, then they should be surprised to see the car reappear from behind the screen when the toy mouse is placed in front of or behind the track (expected or possible event), and not when the toy mouse is

placed on the track (unexpected or impossible event). At 4 months of age, females, but not males, looked reliably longer at the toy car event when the mouse was placed on the track than when it was placed behind the track, as if the females did not expect the toy car to reappear from behind the screen when the path was blocked (Baillargeon & DeVos, 1991). By 6 months of age, both males and females looked reliably longer at the toy car event when the track was blocked (Baillargeon, 1986). In another series of experiments, Baillargeon, Graber, DeVos, and Black (1990) tested 5.5-month-old infants' ability to remember the relative location of a toy and a barrier and to identity the appropriate actions needed for retrieval of the toy. For example, in one experiment, infants saw a toy bird sitting next to a barrier; the bird and the barrier were then hidden by a screen. Next, a hand retrieved the toy bird from behind the right edge of the screen. In the unexpected or impossible event, the barrier sat to the right of the toy bird, blocking the hand's access to the bird. In the expected or possible event, the barrier sat to the left of the toy bird, allowing for direct access to the bird. The infants looked reliably longer at the unexpected than the expected test event, as if they remembered the relative location of the toy bird and the barrier and could identify the appropriate action needed to retrieve the bird.

Together, these two series of experiments suggest that by 5.5 months of age both male and female infants attend to the relative location of objects in a display and can use this information to reason about the outcome of physical events. However, these experiments do not address the issue of location memory directly. In both the toy car and the barrier studies, infants' memory for the relative location of the hidden objects was tested along with knowledge about other physical properties of objects. For instance, to reason correctly about whether the car should reappear from behind the screen, the infants in the toy car study had to (a) assume that one solid object cannot pass through another solid object, (b) expect a moving object to travel on a constant trajectory, *and* (c) remember the position of the toy mouse relative to the track. In a less complicated event, where remembering the location of an object is the primary focus, infants might evidence location memory well before 5.5 months of age.

If full-term infants are able to represent and remember the location of a hidden object, can healthy preterm infants do the same? Or will the experience of being born prematurely alter the development of location memory abilities? Although physical reasoning abilities have not been investigated in preterm infants, visual paired comparison and dishabituation procedures have been used to examine preterm infants' ability to remember previously viewed stimuli, such as three-dimensional objects or geometric designs. The findings from these studies suggest that preterm infants are less likely than full-term infants to remember previously viewed stimuli (Rose, 1980, 1983; Sigman & Parmelee, 1974). Impaired recognition memory abilities are often related to gestational age at birth, birthweight, and the severity of neonatal medical complications experienced (Sigman, Cohen, & Forsythe, 1981; Siqueland, 1981; Werner & Siqueland, 1978). Preterm infants born younger and smaller, and who have experienced more complicated medical histories, perform less well on recognition memory tasks than preterm infants born older and larger, and who have experienced fewer medical complications (Sigman et al., 1981; Siqueland, 1981; Werner & Siqueland, 1978). Although healthy preterm infants with uncomplicated medical histories can perform as well on some visual recognition tasks as full-term infants, this is not always the case (Siqueland, 1981). Finally, other researchers have found that even uncomplicated preterm birth has long-term consequences for the development of some cognitive abilities (Als, Duffy, McAnulty, & Badian, 1989; Duffy, Als, & McAnulty, 1990). Together, these findings raise questions about (a) the types of cognitive functions that are most sensitive to premature exposure to the extrauterine environment and (b) whether observed deficits are due to preterm birth, alone, or to medical complications above and beyond preterm birth.

When preterm–full-term differences in recognition memory abilities have been reported, they are often attributed to differences in information processing abilities. Preterm and full-term infants often evidence different patterns of attention during recognition memory tasks. Compared to full-term infants, preterm infants evidence longer length of looks, take longer to habituate to a visual stimulus, and need a longer encoding period for later recognition (Rose, Feldman, McCarton, & Wolfson, 1988; Spungen, Kurtzberg, & Vaughan, 1985). These differences are thought to reflect differences in the speed and efficiency of information processing. Infants who take longer to habituate to a stimulus and evidence longer length of looks during habituation trials are considered "slow" information processors; infants who habituate quickly and have shorter looks are considered "fast" information processors (Bornstein & Sigman, 1986; Colombo, Mitchell, Coldren, & Freeseman, 1991). However, it is not clear that healthy preterm and full-term infants always evidence different patterns of attention. Reported preterm–full-term differences in attention abilities, like some memory abilities, may be due to medical complications beyond preterm birth itself.

The purpose of this research was to (a) investigate the development of location memory in young infants directly, (b) compare the location memory abilities of healthy preterm infants to those of healthy full-term infants, and (c) investigate group differences in attentional abilities. The paradigm used was adapted from the one designed by Baillargeon and colleagues to use with 8-month-old infants (Baillargeon et al., 1989). In this task, infants saw a toy lion sitting at one of two identical locations of hiding. Next, two screens were raised to hide both locations. After a brief delay, a hand retrieved the lion from either the correct location (expected event) or the incorrect location (unexpected event). If infants remember the location of the lion, they should expect the lion to reappear at the correct, but not the incorrect, location. In Experiment 1, healthy preterm and full-term infants were tested longitudinally at 2.5, 4.5, and 6.5 months of age. The delays used at each age were 5, 10,and 30 s, respectively. Experiment 1A was conducted to investigate the possibility that the infants in Experiment 1 were responding to a change in arm orientation when the lion was retrieved, rather than to a change in location. To investigate preterm–full-term differences in attention, mean length of looks and trial length (i.e., time taken to reach familiarization criteria) during the encoding period were examined. These two measures were chosen for several reasons. First, mean length of looks appears to be the most stable and reliable characteristic of attention over both short-and long-term test–retest intervals

(Colombo, Mitchell, & Horowitz, 1988; Colombo, Mitchell, O'Brien, & Horowitz, 1987) and shows the most consistent and robust developmental change (Colombo & Mitchell, 1990). Second, mean length of looks and trial length during encoding often predict memory abilities (Baillargeon, 1987; Colombo & Mitchell, 1990). A reliable decrease in attention to the encoding and test events after 2.5 months of age was observed in Experiment 1. Experiment 2 was conducted to investigate whether this decrease could be attributed to repeated exposure to the location memory task or to longer delay intervals.

EXPERIMENT 1

Method

Subjects

Subjects were 21 full-term (14 male, 7 female) and 18 preterm (11 male, 7 female) infants tested at 2.5, 4.5, and 6.5 months of age. The mean ages of the full-term infants were 2 months 17 days (SD = 6 days), 4 months 19 days (SD = 5 days), and 6 months 17 days (SD = 4 days). The mean corrected ages of the preterm infants (i.e., age from expected due date) were 2 months 16 days (SD = 5 days), 4

months 16 days (SD = 5 days), and 6 months 17 days (SD = 6 days). Two additional infants were tested but eliminated from the study because they completed only one of the three test sessions. The preterm infants were recruited from the special care nurseries of three major hospitals in a metropolitan area in the southwestern United States. The full-term infants were recruited from the normal newborn nursery of one of the same hospitals. All infants were singletons, weight appropriate for gestational age, and free of known neurological insult, genetic and chromosomal abnormalities, infection, or disease. Perinatal variables are listed in Table 1. The infants were part of a larger study, and parents were paid $5.00 for participation in each test session. Most subjects were Caucasian (Caucasian = 26, Mexican American = 9, other = 4) and from middle-class families. The mean age of the mothers was 29.1 years (range = 19–42 years). The majority of the mothers had some education past high school (n = 28) and worked at least part time outside the home (n = 24).

Apparatus

The apparatus consisted of a wooden box 105.5 cm high, 68.5 cm wide, and 47.0 cm deep. The infant sat facing an opening 29.0 cm high and 68.5 cm wide. The roof of the apparatus slanted upward, increasing the height of the opening to 43.0 cm at the back wall. The front edge of a small stage, 21.0 cm deep and 68.5 cm wide, was raised 8.5 cm from the floor and sloped gently upwards towards the back of the apparatus. The front edge of the stage lay 20.5 cm from the front opening of the apparatus. The floor, walls, roof, and stage of the apparatus were covered in

TABLE 1
Perinatal Variables for the Preterm (n = 18)
and Full-Term (n = 21) Infants

Perinatal Variables	Preterm M (SD) Range	Full Term M (SD) Range
Gestational Age at Birth (weeks)	34.06 (0.80) 32–35	39.62 (0.86)** 38–41
Birthweight (grams)	2150 (240) 1800–2570	3300 (330)** 2700–3780
APGAR at 1 M	7.06 (1.35) 4–9	7.95 (0.67)* 7–9
APGAR at 5 M	8.39 (0.85) 6–9	8.95 (0.22)* 8–9
Length of Hospital Stay (days)	10.61 (6.17) 3–27	2.14 (1.28)** 1–6
Oxygen Support Required:		**
None	4	18
Blow-By at Birth	4	3
Hood or Nasal Cannula	10	0
0–24 hours	7	0
25–48 hours	1	0
49–72 hours	2	0

Note. A one-way ANOVA was conducted on all continuous variables. A chi-square was performed on type of oxygen support required (none/blow-by/hood).
*$p \leq .01$. **$p \leq .001$.

black felt. Across the back of the stage lay a piece of Plexiglas, 36.5 cm long and 4.5 cm wide, within a metal track. The Plexiglas was covered with a strip of Velcro to which objects could be attached. On top of the metal track lay two identical red plastic ovals, 9.5 cm wide and 7.0 cm deep. These ovals marked the two locations of hiding. The edge of the ovals lay 5.0 cm from the back wall and 10.5 cm from the side wall. Directly in front of each red oval stood a yellow cardboard screen, 16.5 cm tall and 12.75 cm wide, attached to a wooden dowel. The wooden dowel exited the apparatus from a small hole in the right wall. Attached to the end of the dowel was a metal lever. The screens remained in an upright position when the lever was placed next to a magnet on the outside wall of the apparatus and could be lowered to lay flat against the floor of the stage when the lever was released. The back wall of the apparatus was made of cardboard and was covered with black cloth. Two small holes, 8 cm high and 7 cm wide, were cut into the back wall and were covered by pieces of black cloth to mask their existence. The holes were located directly behind each red oval and were occluded by the screens when the screens were in an upright position. A 44 cm long slit was cut into the upper portion of the back wall to allow for the visible entrance and exit of a gloved hand. Two tubular lights (20 cm long), each with a 40 watt light bulb, were attached to the side walls near the front of the apparatus. The lights were positioned to brightly illuminate the stage without producing telltale shadows. A black curtain could be raised from the floor of the apparatus to cover the opening of the apparatus.

A yellow plastic lion, 8 cm high and 7 cm wide, was placed in either the right or left oval at the beginning of each trial. On the bottom of the lion was a small piece of Velcro so that the lion could be securely placed on the Plexiglas track. The lion squeaked when pressure was applied. During the pretest and test trials, a right hand wearing a white nylon glove and a silver jingle bracelet entered the apparatus from the slit in the back wall. The glove was 58 cm long and covered both the hand and arm of the experimenter. Testing was conducted in a dark room with overhead track lighting illuminating the infant's face. A video camera mounted near the ceiling recorded a head-on view of the infant's eyes and face. The walls to the right and to the back of the infant were painted off-white. To the left of the infant was an off-white curtain attached to a movable wood frame, isolating the infant from the rest of the room.

Procedure

The infant sat in an infant seat centered with the front opening of the apparatus. The infant seat was placed on a platform raised approximately 37 cm from the floor. The parent watched the infant on a video screen located behind the apparatus. Occasionally the parent sat next to the infant or the infant was placed on the parent's lap. In these cases, the parent was instructed to refrain from interacting with the infant during the test session.

The infant's looking behavior was monitored by an observer who viewed the infant on the video screen. The observer was blind to the order in which the events were presented. The observer held a handgrip linked to a Compaq PC and depressed a button when the infant attended to the events. Sixty-five of the 113 sessions were later restored by an independent second observer. Interobserver

reliabilities were calculated for the familiarization period and test event using Pearson's r. The mean reliability coefficient was .965.

Each infant saw two pretest trials and four test trials. One experimenter produced all pretest and test trials. In the following description of events, the numbers in parentheses indicate the time taken to produce the actions described. A schematic representation of the test trials is presented in Figure 1.

Pretest Trials. At the beginning of the test session, infants saw two pretest displays to acquaint them with the two locations of hiding. Pretest trials began with the curtain raised. When the curtain was lowered, the infant saw the lion sitting in one of the red ovals. A gloved hand entered the apparatus through the slit in the back wall (2 s), gently squeaked the lion (1 s), and exited through the back wall (2 s). Next, the lion was "jiggled" (3 s) by pulling on the fishing line attached to the track (the ovals did not move) and then sat unmoving until the computer signaled the end of the pretest trial. Pretest trials ended when the infant (a) looked away from the display for 2 consecutive s after having looked for at least 5 cumulative s or (b) looked at the display for 10 cumulative s without looking away for 2 consecutive s. Half the infants saw the lion in the right oval first, the other half saw the lion in the left oval first.

Test Trials. Following the two pretest trials, infants saw four test trials. Each test trial consisted of (a) a familiarization period, (b) a delay period, and (c) a test event. The *familiarization period* began with the curtain raised. When the curtain was lowered, the infant saw the lion sitting in one of the two red ovals. A gloved hand entered the apparatus through the slit in the back wall (2 s), gently squeaked the lion (1 s), and exited through the back wall (2 s). Next, the lion was "jiggled" (3 s) by pulling on the fishing line attached to the track and then sat unmoving (5 s). The last 8-s sequence was repeated until the familiarization period ended. Criterion for termination of the familiarization period varied for odd- and even-numbered trials. On odd-numbered trials, the familiarization period ended when the infant (a) looked away from the display three times, 2 s each time after having looked for at least 10 cumulative s or (b) looked at the display for 30 cumulative s. On even-numbered trials, the familiarization period ended when the infant (a) looked away one time for 2 consecutive s after having looked for at least 5 cumulative s or (b) looked for 10 cumulative s. Half the infants saw the lion on the left for the first two trials, and half saw the lion on the right for the first two trials. Pilot data suggested that relaxing the familiarization criterion for even-numbered trials, when the object was hidden at the same location as the previous trial, helped to shorten the test session without affecting memory performance. When the computer signaled the end of the familiarization period, the screens were raised to occlude both locations (2 s). If the infant was not watching as the screens were raised, the experimenter called the infant's name to regain attention. This was to ensure that the infant saw the object as it was hidden.

The familiarization period was followed by a *delay period.* The delays used were 5 s at 2.5 months, 10 s at 4.5 months, and 30 s at 6.5 months. These are delay intervals at which infants perform successfully on other visual recognition memory tasks (e.g., Diamond, 1990). During the first 3 s of the delay period, the experimenter surreptitiously placed an identical lion behind the screen hiding the empty

Expected Event
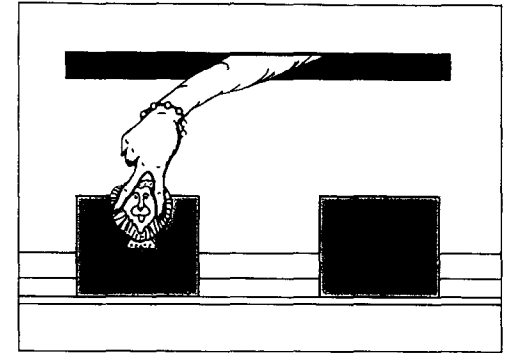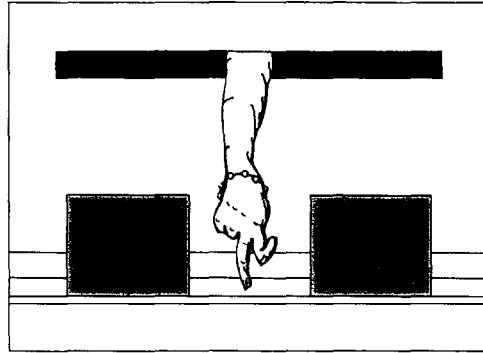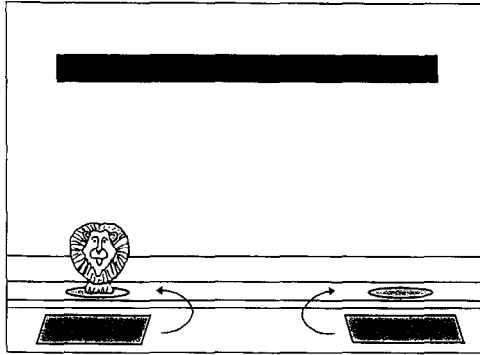
Unexpected Event

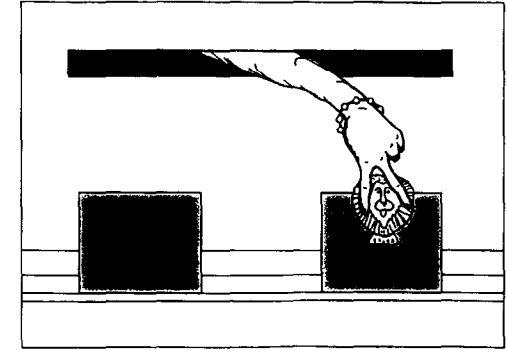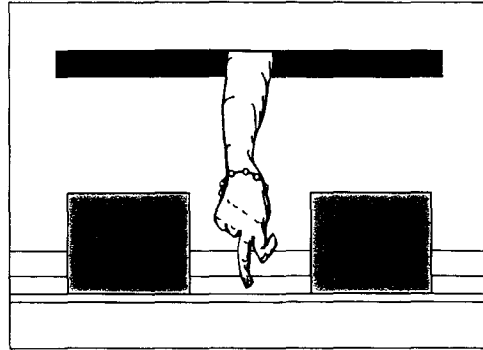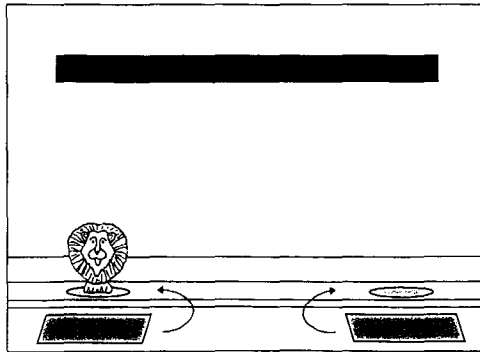Figure 1. Schematic representation of the location memory task. The infant views the lion sitting at one of two identical locations of hiding. Two screens are then raised to hide both locations, and a delay period is imposed. In the *expected event*, the lion is retrieved from the correct location of hiding. In the *unexpected event*, the lion is retrieved from the incorrect location of hiding.

oval. The lion was inserted before both expected and unexpected test events. During the 10-s and 30-s delays, the experimenter also put on a silver jingle bracelet. The gloved hand entered the display box from the slit in the back wall at a point above, and centered between, the two screens. In the 5-s delay, the hand remained out of view for 2 s and then entered the display (1 s), waved (1 s), and moved to retrieve the lion (1 s). In the 10-s delay, the hand remained out of view for 2 s, then entered the display (1 s), waved (1 s), tiptoed down the stage and back up the stage (4 s), waved (1 s), and moved to retrieve the lion (1 s). In the 30-s delay, the hand remained out of view for 8 s, then entered the stage holding a dog rattle (1 s), "marched" the dog rattle down and back up the stage (9 s), exited the stage and returned without the rattle (2 s), tiptoed down and back up the stage (8 s), waved (1 s), and moved to retrieve the lion (1 s). The dog rattle was used during the 30-s delay to maintain the infant's interest and was necessary to prevent fussiness. A similar procedure was used by Baillargeon et al. (1989) and is not considered a problem for interpretation. The computer acted as a metronome, ticking once each second. The experimenter used the computer ticking to adhere to the above schedule.

Following each delay period, infants saw a *test event*; either an expected or unexpected event. In the expected event, the infant saw the hand retrieve the lion from behind the screen where it was hidden. The lion was lifted off the Velcro-covered track (1 s), squeaked gently after it appeared from behind the screen (1 s), and held in front of the screen until the computer signaled the end of the test event. The unexpected event was identical to the expected event except that the infant saw the hand retrieve the lion from behind the other screen. Expected and unexpected events were seen on alternating trials. A Velcro sound accompanied both the expected and the unexpected events. The test event ended when the infant (a) looked away for 2 consecutive s after having looked for at least 10 cumulative s or (b) looked for 60 cumulative s without looking away for 2 s. The curtain was then raised, and the experimenter prepared for the next familiarization period. Each infant saw two pairs of expected and unexpected events.

Each infant was tested once at each of the three ages. At 2.5 months, 2 infants were not tested (scheduling conflict and fussiness) and 5 infants contributed only one pair of expected and unexpected test events (3 due to fussiness and 2 due to procedural error). At 4.5 months, 1 infant was not tested (scheduling conflict) and 2 infants contributed only one pair of test events (fussiness). At 6.5 months, 1 infant was not tested (scheduling conflict) and 5 infants contributed only one pair of test events (3 due to fussiness and 2 due to procedural error). These were different infants at each age, and all were included in the analysis. Order of event (expected or unexpected event seen first) and order of side of presentation (lion seen on the left or the right first) were counterbalanced across infants and ages. Preliminary analyses revealed no significant main effect of order of event, order of side of presentation, or gender on mean looking times. There were also no significant interactions involving these factors and events. Consequently, the data were collapsed in subsequent analyses. Looking times to the expected and unexpected test events were averaged across the two test pairs.

Attention Measures

To investigate group differences in attentional abilities, mean length of looks and trial length during the encoding period were examined. The mean length of looks was calculated by dividing the total looking time during the familiarization period by the number of looks away. Due to computer error, mean length of looks was unavailable for 1 preterm infant at 2.5 months of age. Trial length was the total time the infant spent looking before meeting familiarization criteria (i.e., cumulative looking time). Because the criteria for ending the odd- and even-numbered trials differed, the attention measures were calculated separately for these trials. Preliminary analysis indicated that on the even-numbered trials, where the criteria for ending the trial was either a 2-s look away or 10-s cumulative looking, the majority of infants (69% of the 2.5-month-olds, 64% of the 4.5-month-olds, and 62% of the 6.5-month-olds) looked for 10 cumulative s. As a result, mean length of looks and trial length varied little on these trials. On the odd-numbered trials, where the criteria for ending the trial was either a 2-s look away or 30-s cumulative looking, the majority of infants reached familiarization criterion before accumulating 30 s of looking. This allowed for variability in both the mean length of looks and trial length. Consequently, only the data from the odd-numbered familiarization trials were used. Mean length of looks and trial length were averaged across the two odd-numbered trials.

Results

Location Memory

The infants' looking times during the pretest trials were analyzed by means of a $2 \times 2 \times 3$ mixed-model analysis of variance (ANOVA) with infant group (preterm, full-term) as the between-subjects variable and side (left or right) and age (2.5, 4.5, and 6.5 months) as the within-subject variables. An unbalanced design was used because of unequal cell sizes. There were no significant main effects or interactions involving infant group, side, or age. Looking times did not differ reliably when the lion was viewed on the left ($M = 9.27$ s, $SD = 1.42$) or the right ($M = 9.29$ s, $SD = 1.42$) during the pretest trials.

Mean looking times to the expected and unexpected events are displayed in Table 2. The infants' looking times to the test events were analyzed by means of a $2 \times 2 \times 3$ mixed-model ANOVA with infant group (preterm, full-term) as the between-subjects variable and with event (expected or unexpected) and age (2.5, 4.5, and 6.5 months) as the within-subject variables. The main effect of event was significant, $F(1, 37) = 16.86$, $p < .001$. Planned comparisons indicated that the infants looked reliably longer at the unexpected than expected test event at 2.5 months, $t(36) = 2.61$, $p = .013$, 4.5 months, $t(37) = 3.53$, $p = .001$, and 6.5 months, $t(37) = 2.03$, $p = .05$, of age. The main effect of age was also significant, $F(2, 70) = 15.98$, $p < .001$. Post hoc analyses using the Tukey test

TABLE 2
Mean Looking Times (in Seconds) to the Expected and Unexpected
Test Events for the Preterm and Full-Term Infants

	Expected Event	Unexpected Event
Age/Infant Group	M (SD)	M (SD)
2.5 Months		
Preterm (n = 17)	30.8 (13.9)	36.6 (16.1)
Full Term (n = 20)	33.0 (15.8)	40.9 (13.4)
Total	32.0 (14.8)	38.9 (14.6)
4.5 Months		
Preterm (n = 17)	18.5 (8.3)	24.8 (10.0)
Full Term (n = 21)	22.9 (10.1)	27.4 (14.8)
Total	21.0 (9.5)	26.2 (12.8)
6.5 Months		
Preterm (n = 18)	22.9 (13.0)	25.0 (12.1)
Full Term (n = 20)	21.1 (11.4)	24.9 (12.5)
Total	22.0 (12.0)	25.0 (12.2)

Note. Delay intervals used were 5, 10, and 30 s at each age, respectively.

indicated that the infants' looked reliably longer to the test events as 2.5 months of age ($M = 35.5$, $SD = 12.3$) than at 4.5 ($M = 23.6$, $SD = 10.6$; $p < .01$) and 6.5 ($M = 23.5$, $SD = 11.2$; $p < .01$) months of age. There were no other significant main effects or interactions. The number of infants who looked longer at the unexpected event, at each age respectively, were 23/37, 28/38, and 26/38.

Attention
Mean trial length and mean length of looks are displayed in Table 3. The infants' trial lengths were analyzed by means of a 2 × 3 mixed-model ANOVA with infant group (preterm, full-term) as the between-subjects variable and age as the within-subject variable. There were no significant main effects, or interactions, involving infant group or age on the length of

the familiarization period. The infants' mean length of looks were analyzed by means of a 2 × 3 mixed-model ANOVA with infant group as the between-subjects variable and age as the within-subject variable. There was not a significant main effect of infant group on the mean length of looks. However, there was a significant main effect of age on the mean length of looks, $F(2, 69) = 8.44$, $p < .001$. Post hoc analyses using the Tukey test revealed that at 2.5 months of age infants had significantly longer mean length of looks than they did at 4.5, $p < .01$, and 6.5, $p < .01$, months of age. Together, these results suggest that the preterm infants did not take longer to encode the location of the object and were not more likely to fixate continuously during the encoding period than the full-term infants. However, the infants were more likely to evidence shorter looks at

TABLE 3
Mean Trial Length and Mean Length of Looks (in Seconds) During
the Familiarization Period for the Preterm and Full-Term Infants

	Age (Months)		
	2.5	4.5	6.5
M (SD) Trial Length			
Preterm (n = 17,17,18)	27.1 (4.5)	25.7 (6.2)	25.9 (5.9)
Full Term (n = 20,21,20)	26.3 (5.8)	25.6 (4.3)	27.3 (3.1)
Total	26.7 (5.2)	25.7 (5.1)	26.6 (4.6)
M (SD) Length of Looks			
Preterm (n = 16,17,18)	9.2 (6.7)	6.3 (3.5)	6.6 (3.9)
Full Term (n = 20,21,20)	12.3 (8.4)	5.2 (2.3)	6.3 (3.2)
Total	10.9 (7.7)	5.7 (2.9)	6.5 (3.6)

the older ages. This decrease may reflect a developmental change in the speed and efficiency of visual information processing (Colombo & Mitchell, 1990). A similar pattern of results was obtained with overall looking times to the test events.

Discussion

The infants in Experiment 1 looked reliably longer at the unexpected than expected test event, as if they remembered the location of the lion and were surprised to see it reappear at the other location. However, there is an alternative explanation for this result. The infants may have been responding to a change in arm orientation rather than to a change in location. In the familiarization period, the hand entered the apparatus and squeaked the lion at one of the two locations. In the test event, the hand entered the apparatus and retrieved the lion from either (a) the correct location, in which case the orientation of the experimenter's arm was the same as seen in the familiarization period, or (b) the incorrect location, in which case the orientation of the experimenter's arm was disparate from that seen in the familiarization period. Consequently, it is possible that the infants were responding to a novel arm orientation rather than to the reappearance of the lion at the incorrect location. To control for this possibility, an independent group of 2.5-, 4.5-, and 6.5-month-old infants was tested using a similar procedure except that the lion was absent from the display. That is, the arm was seen at each location but the lion was never hidden or retrieved. If the infants in Experiment 1 were responding to a change in arm orientation and not to a change in object location, then they should look longer at the test event when the experimenter's arm is in a different, rather than the same, orientation as that seen in the familiarization period. However, if the infants in Experiment 1 were responding to a change in object location and not arm orientation, then they should look equally at the two test events.

EXPERIMENT 1A

Method

Subjects

Subjects were 24 healthy full-term infants tested at one of three ages; 2.5, 4.5, and 6.5 months. An equal number of infants, and an equal number of males and females, were tested at each age. These were different infants than those tested in Experiment 1. Ten additional infants were tested but not included in the analysis (7 due to fussiness and 3 due to procedural error). The mean age for each group was 2 months 13 days (SD = 7 days), 4 months 17 days (SD = 3 days), and 6 months 16 days (SD = 5 days). Infants were recruited from the birth announcements in the local newspaper. Parents were contacted by phone and follow-up letters and were not paid for their participation in this experiment. Most subjects were Caucasian and from middle-class families. The mean age of the mothers was 32 years (range = 22–43 years). The majority of the mothers had some education past high school (n = 20) and many worked at least part-time outside the home (n = 10).

Apparatus

The same apparatus as described for Experiment 1 was used for experiment 1A.

Procedure

The procedure for Experiment 1A was similar to that described for Experiment 1 except that the lion was never present in the display. During the familiarization period, the hand entered the stage, made squeezing motions at one location (i.e., similar to the motion made in Experiment 1 when the lion was squeaked), and exited the stage. After the infant reached familiarization criterion, the two screens were raised. In the same orientation test event, the hand entered the stage, made the movements appropriate for the delay interval, and then moved to the location indicated in the familiarization period. The hand remained positioned over the screen with rounded fingers (i.e., similar to that seen in Experiment 1 when the lion was held) until the end of the trial. The different orientation test event was similar to the same orientation test event except that the hand was positioned over the other location. Because the lion was not seen in the test trials, pretest trials were eliminated.

Each infant saw two pairs of same-arm orientation and different-arm orientation test events. Order of event (same- or different-arm orientation) and order of left–right (arm oriented to the left or right first) were counterbalanced across infants and ages. The same delays used in Experiment 1 were used here: 5 s at 2.5 months, 10 s at 4.5 month, and 30 s at 6.5 months. One fourth of the test sessions were later restored by an independent second observer. Interobserver reliabilities were calculated using a Pearson's *r* and were based on looking times for each familiarization and test event. The mean reliability coefficient was .92. Looking times to the two test events were averaged across the two test pairs.

Results

The infants' looking times to the test events were analyzed by means of a 2 × 3 mixed-model ANOVA with age as the between-subjects variable and event (same- or different-arm orientation) as the within-subject variable. There were no significant main effects involving event or age, nor a significant interaction between these two variables. The infants looked about equally at the same-arm orientation (M = 20.9, SD = 10.5) and different-arm orientation (M = 20.5, SD = 13.4) events, as if they had no preference

for orientation of the experimenter's arm during the test event.

Discussion

Together, the results of Experiments 1 and 1A suggest that infants as young as 2.5 months of age can remember the location of a hidden object and expect the object to remain at that location. After seeing a toy lion hidden at one of two identical locations, the infants in Experiment 1 looked reliably longer when the lion was retrieved from the incorrect than the correct location. Although it is possible that the infants were responding to a change in arm orientation rather than to a change in location, the results of Experiment 1A argue against this interpretation. The infants in Experiment 1A looked about equally at the same-arm orientation and different-arm orientation test event, showing no reliable preference for a change in the orientation of the experimenter's arm.

In Experiment 1, there were no differences between the preterm and full-term infants in memory for the location of the hidden object or in attention behaviors during the encoding period. However, looking times to the test events and mean length of looks during the encoding period decreased reliably with age. Aside from developmental changes in attentional abilities, there are at least two possible explanations for the decrease in looking times to the test events: repeated exposure to the test events and longer delay intervals. Likewise, the decrease in mean length of looks during the encoding period could be due to repeated exposure to the location memory task. (Because the delay interval occurred after the encoding period, it is unlikely that delay influenced mean length of looks during the encoding period.) Experiment 2 was conducted to investigate whether repeated exposure to the location memory task and/or longer delay intervals were responsible for the decrease in attention to the encoding and test events. In Experiment 2, an independent sample of 6.5-month-old infants was tested using a similar procedure. Two delay intervals, 30 s and 60 s, were used. If the decrease in attention to the encoding and test events observed in Experiment 1 was due to repeated testing, then 6.5-month-old infants who have not seen the events before (Experiment 2) should evidence reliably longer looking times to the test events, and reliably longer mean length of looks during

the encoding period, than 6.5-month-old infants who have seen the events twice before (Experiment 1). In contrast, if repeated exposure to the test events was not responsible for the decrease in attention to the encoding and test events, then the 6.5-month-old infants in Experiments 1 and 2 should evidence similar attention behaviors. If the length of the delay interval influenced looking times to the test events in Experiment 1, then the infants in Experiment 2 should evidence shorter looking times after a longer delay interval. In contrast, if the length of the delay interval was not responsible for the decrease in attention to the test events, then the infants' looking times should not vary as a function of the delay interval.

EXPERIMENT 2

Method

Subjects

Twenty-four 6.5-month-old healthy full-term infants participated in Experiment 2. An equal number of males and females were tested. These were different infants than those tested in Experiments 1 and 1A. Five additional infants were tested but not included in the analysis (3 due of procedural error and 2 due of fussiness). The mean age of the infants was 6 months 24 days ($SD = 8$ days). Infants were recruited from the birth announcements in the local newspaper. Parents were contacted by phone and follow-up letters. Parents were not paid for their participation in this experiment. Most subjects were Caucasian and were from middle-class families. The mean age of the mothers was 29.8 years (range = 21–39 years). The majority of mothers had some education past high school ($n = 18$), and half worked at least part-time outside the home ($n = 12$).

Apparatus

The same apparatus as described for Experiment 1 was used for Experiment 2.

Procedure

The procedure for pretest and test trials was the same as that described for Experiment 1, except that each infant saw eight test trials; there were two pairs of expected and unexpected events at each of the two delay intervals. Delays of 30 s and 60 s were used. During the 60-s delay, the gloved hand with the jingle bracelet remained out of view for 9 s, then entered the display holding a dog rattle (1 s), "marched" the dog rattle down and back up the stage (20 s), exited the stage and returned without the rattle (10 s), tip-toed down and back up the stage (18 s), waved (1 s), and moved to retrieve the lion (1 s). Order of event (expected or unexpected event seen first), side of presentation (lion seen on the left or right first), and delay (short or long delay first) were counterbalanced across infants. Four infants contributed only three of the four test pairs (3 due to fussiness and 1 due to procedural error) but were still included in the analyses. One third of the test sessions were later restored by an independent second observer. Interobserver reliabilities were calculated using a Pearson's *r* and were

based on looking times for each familiarization and test trial for that infant. The mean reliability coefficient was .968. Preliminary analyses revealed that there were no significant main effects of order of event, order of side of presentation, order of delay, or gender. In addition, there were no significant interactions involving these variables and test event. Consequently, the data were collapsed in subsequent analyses. Looking times to the expected and unexpected test events, for each delay, were averaged across the two test pairs.

Results

Analysis of the infants' looking times during the pretest trials indicated that looking times did not vary reliably when the lion was viewed on the left ($M = 9.5$ s, $SD = 1.3$) or the right ($M = 9.8$ s, $SD = 0.7$). The infants' looking times to the test events were analyzed by means of a 2 × 2 mixed-model repeated measures analysis of variance with event (expected or unexpected event) and delay (30 s and 60 s) as the within-subject variables. The main effect of event was significant, $F(1, 23) = 16.47$, $p < .001$, indicating that the infants looked reliably longer at the unexpected than expected test event. The main effect of delay was not significant, and the interaction between delay and event was not significant. Planned comparisons indicated that the infants looked reliably longer at the unexpected than expected event after the 30-s delay (expected event $M = 18.3$, $SD = 8.8$; unexpected event $M = 24.6$, $SD = 11.5$), $F(1, 23) = 6.04$, $p = .022$, and the 60-s delay (expected event $M = 17.6$, $SD = 5.9$; unexpected event $M = 23.0$, $SD = 11.6$), $F(1, 23) = 4.30$, $p = .05$. The number of infants who looked longer at the unexpected event after the short and long delays, respectively, were 21/24 and 17/24. These results suggest that the infants remembered the location of the lion after both delay intervals and that the length of the delay did not reliably influence overall looking times to the test events.

Across Experiment Analyses

Across experiment analyses were conducted to investigate whether the 6.5-month-old infants in Experiment 1, who were tested longitudinally (i.e., had two previous exposures to the events), responded like the 6.5-month-old infants in Experiment 2, who were tested cross-sectionally (i.e., had no previous experience with the events) on the location memory task. Only data from the 30-s delay were used. As previously reported, 3 infants from Experiment 1

missed one of the first two test sessions. To ensure that all infants from the longitudinal sample had equal experience with the test events, these 3 infants were excluded from the analysis. One additional infant was not tested at 6.5 months and was also excluded from the analysis.

To investigate the decrease in attention to the encoding events, a one-way ANOVA was conducted on the infants' mean length of looks during the familiarization period (odd-numbered trials only) with experiment (Experiment 1 or 2) as the between-subjects variable. The mean length of looks of the 6.5-month-old infants from Experiments 1 ($M = 6.4$, $SD = 3.6$) and 2 ($M = 7.3$, $SD = 3.6$) did not vary reliably. This suggests that the decrease in mean length of looks observed in Experiment 1 was not due to repeated exposure to the location memory task.

Next, the infants' looking times to the test events were analyzed by means of a 2 × 2 mixed-model ANOVA with experiment as the between-subjects variable and with event as the within-subject variable. There was a significant main effect of event, $F(1,57) = 15.36$, $p < .001$, indicating that the infants looked reliably longer at the unexpected ($M = 25.3$, $SD = 11.9$) than expected ($M = 20.9$, $SD = 11.1$) test event. Mean looking times to the unexpected and expected test events for the longitudinal sample ($n = 35$) were 25.7 s ($SD = 12.4$) and 22.6 s ($SD = 12.2$), respectively. The main effect of experiment and the interaction between event and experiment were not significant. These results suggest that the looking times to the test events did not vary reliably as a function of having seen the test events before. In addition, sensitivity to the unexpected test event was not reliably influenced by previous exposure to the test events.

Discussion

The 6.5-month-old infants in Experiment 2 looked reliably longer at the unexpected than expected test event after both the 30-s and 60-s delay intervals. This finding suggests that the infants remembered the location of the lion and found its reappearance at the incorrect location incongruent with the hiding event, even after the longer delay interval. Across-study comparisons revealed that the 6.5-month-old infants from Experiments 1 and 2 did not vary reliably in their attention during the encoding period or in their attention to the test events. In addition,

the longer delay interval used in Experiment 2 did not reliably influence looking times to the test events. Together, these findings suggest that the decrease in looking times to the test events observed in Experiment 1 was not due to repeated exposure to the test events or to the longer delay intervals. Likewise, repeated exposure to the location memory task was not responsible for the decrease in mean length of looks during the encoding period. Although it is still possible that the shorter delay intervals used in Experiment 1 led to longer looking times to the test event, because the 6.5-month-old infants in Experiment 2 were not tested at the same delay interval as the 2.5-month-old infants in Experiment 1 (i.e., 5 s), our data suggest that this is probably not the case.

GENERAL DISCUSSION

The results of these experiments suggest that infants as young as 2.5 months of age can represent and remember the location of a hidden object. After seeing a toy lion hidden at one of two identical locations, the infants in Experiment 1 looked reliably longer when the lion reappeared at the incorrect than correct location, as if they found the reappearance of the lion at the incorrect location unexpected. The results of a control experiment (Experiment 1A) suggest that the differential responding to the test events was due to a change in location and not to superficial differences (i.e., orientation of the experimenter's arm) between the two events. The infants looked reliably longer at the reappearance of the lion at the incorrect location after delays of 5 s at 2.5 months of age, 10 s at 4.5 months, and 30 s at 6.5 months. There were no significant differences between the preterm and full-term infants. In addition, in Experiment 2, the 6.5-month-old full-term infants looked longer at the reappearance of the lion at the incorrect location after a delay as long as 60 s. Together, these findings suggest that even the youngest infants remembered the location of the hidden lion and expected it to reappear at the correct location only.

Demonstration of location memory abilities in infants as young as 2.5 months of age provides converging evidence that even very young infants are capable of representing the physical and spatial properties of occluded objects (Baillargeon, 1986; Baillargeon & DeVos, 1991; Spelke et al., 1992). In addition,

these findings suggest that location memory may be a fundamental component of early cognitive abilities. Young infants not only expect objects to be unitary, bounded, and spatiotemporally continuous (Spelke, 1990), and to continue to exist when hidden (Baillargeon, 1987), they also expect a hidden object to maintain it's original position in space and to reappear at that location only. Young infants are capable of remembering a hidden object's location in space, at least with respect to their own body, even though they are unable to express this knowledge through a manual response.

These findings raise several interesting questions about the way that infants encode and represent location information. For example, how precise is infants' representation of object location? Recent research suggests that infants are very good at remembering the location of an object relative to other objects in a display (Baillargeon & DeVos, 1991; Baillargeon et al., 1990). However, remembering the location of an object without a notable point of reference appears to be more difficult. Using a similar location memory task, Wilcox, Rosser, and Nadel (1994) recently reported that 6.5-month-old infants have difficulty remembering the location of a hidden object when four identical locations are used. Infants' response to the reappearance of an object at an incorrect location is differentially influenced by boundary information. When a hidden object reappears at a location that was previously unoccupied, and that location is near a boundary, infants respond to the change in location. In contrast, when a hidden object reappears at a location that was previously unoccupied, and that location is not near a boundary, infants do not respond to the change in location. In addition, results obtained by Baillargeon (1991) suggest that 4.5-and 6-month-old infants are not very precise at representing the exact location, or the height, of a hidden object (although 6-month-old infants are more precise than 4.5-month-old infants). When a second visible object of the same size is present, however, infants are better able to represent the hidden objects' location and height. Together, these results suggest that infants can represent the location of a hidden object, but that encoding of location is somewhat limited. Early in development infants may depend on a qualitative strategy for encoding

an object's location. That is, object location is encoded relative to other objects or landmarks. The ability to use a quantitative strategy, where location is encoded as absolute distance, may be later developing (Baillargeon, 1991). Finally, the studies discussed here have tested infants' ability to remember the location of a hidden object from only one frame of reference, an egocentric frame of reference. Whether young infants are capable of remembering the location of a hidden object using other frames of reference, in a violation-of-expectation paradigm, is an empirical question yet to be addressed.

The preterm infants performed like the full-term infants on the location memory task, suggesting that preterm birth, in and of itself, does not adversely effect the development of location memory abilities. Remember, however, that the preterm infants tested in Experiment 1 were of uncomplicated birth and were seen at corrected age, creating the best possible situation for success. Further research is needed to determine the effect of medical variables, post-natal age, and task difficulty on the development of location memory abilities in preterm infants. Interesting group differences may emerge as a result of differences in the type, timing, and severity of the medical complications experienced. This line of research is particularly interesting in light of current research in the cognitive neurosciences. There appear to be at least two functionally and neuroanatomically distinct memory systems important for the processing of visual information: the object system and the egocentric spatial location system, or the "what" and the "where" systems (Ungerleider & Mishkin, 1982). Current research suggests that the object memory system, important for processing object features, matures early (Bachevalier, 1990), hence, object recognition memory abilities can be observed very early in infancy (Olsen & Sherman, 1983). Young infants can recognize familiar objects and attend to object features when reasoning about events. Less is known about the neural maturation of the egocentric spatial system, although there is evidence for an early developing spatial attention system (Johnson, 1990). However, the research presented here, together with other research demonstrating young infants' ability to reason about the spatial properties of objects, suggests

that the "where" system also matures early. Even very young infants can remember the location of an object, at least from one frame of reference and within small-scale space. Continued investigation of both object and location memory in healthy preterm infants, as well as in preterm infants with varied neonatal medical histories, will provide insight into the functional development of the cognitive systems important for processing featural and location information and the effect of alterations in early experience on the development of these systems.

Finally, group differences in attention during the encoding period were also investigated. The preterm and full-term infants evidenced similar mean length of looks and trial lengths during the encoding period. These findings suggest that the preterm infants were able to encode the location of the object as quickly and as efficiently as the full-term infants. However, the infants' mean length of looks decreased significantly with age. At 2.5 months of age, the infants had reliably longer mean length of looks during the encoding period than they did at 4.5 and 6.5 months of age. The same pattern of results was obtained for looking times to the test events. Across-study comparisons suggest that the changes in attention observed in Experiment 1, to both the encoding and test events, were not due to previous exposure to the events or to the longer delay intervals. What explanation can be given then to the observed changes in attention with age? Current research suggests that mean length of looks during the encoding of visual stimuli reflects the speed and efficiency with which the stimuli are processed (Colombo et al., 1991). For example, infants who have shorter length of looks are more likely than infants with longer looks to recognize previously viewed objects, patterns, or geometric shapes. When given more time to encode the stimulus, infants with longer fixation times evidence recognition memory abilities similar to infants with shorter fixation times. Several possible explanations for developmental changes in information processing abilities have been offered (Colombo & Mitchell, 1990). One possibility is that structural changes in the central nervous system, caused by neural maturation, result in faster and more efficient transmission of visual information. Another possibility is that changes in

the operation of cognitive processes result in more mature and efficient strategies for encoding visual information. Finally, older and more experienced infants may have a larger knowledge base with which to compare visual stimuli, resulting in quicker and more efficient encoding. Although the present data do not speak to the mechanism underlying developmental changes in attention, they do suggest that healthy preterm birth does not affect the development of attentional abilities important for the encoding of visual stimuli.

In summary, the results of these experiments provide converging evidence that young infants possess considerable knowledge of the physical and spatial properties of objects. Young infants expect objects to continue to exist when hidden, can remember the location of a hidden object, and recognize when a hidden object changes its location in space. In addition, when tested at corrected age, healthy preterm infants evidence similar attention and memory abilities, suggesting that uncomplicated premature birth has no apparent effect on the development of these abilities. These findings are in accordance with other reports that preterm infants with uncomplicated medical histories do not always evidence impaired cognitive functioning.

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