

Representation of Object Location in 6.5-Month-Old Infants

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Within a small bounded space, the location of a hidden object can be coded in terms of distance information, general area of hiding, or the boundary of the space. 6.5-month-old infants' use of these three coding strategies was examined using a visual search task. Infants watched as an object was hidden at one of four identical locations. After a short delay (10 s), the object either reappeared at the location where it was hidden (possible event), or reappeared at one of the other three locations (impossible event). Looking behavior was not systematically influenced by the amount of distance the object moved from the original location of hiding or by whether the object was hidden near a boundary. Infants did not appear to code the location of a hidden object in terms of distance information, general area of hiding, or whether it was hidden at a boundary. However, the location of reappearance (i.e., impossible event) did influence looking times. Infants were surprised when the object reappeared at a boundary position that was previously unoccupied. They were not surprised when the object reappeared at a central location. Thus, two factors influenced coding of location: boundary information (but in a different way than specified) and the nature of the change (absence vs. presence of an object). The influence of these two factors on coding of spatial information was discussed.

Young infants not only know that an object continues to exist when hidden (Baillargeon, 1987; Baillargeon, Spelke, & Wasserman, 1985) but also are capable of remembering, and reasoning about, some of the physical and spatial characteristics of that object (Baillargeon, 1986; Baillargeon & DeVos, 1991; Baillargeon, Graber, DeVos, & Black, 1991; Spelke, Breinlinger, Macomber, & Jacobsen, 1992). One of the most rudimentary, but also most important, characteristics of an object is where it is located in space. When an object continues to

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exist it occupies a particular location in space. Likewise, the location of an object can serve as an identifying feature of that object. In fact, infants' reasoning about the physical properties of objects (Spelke, 1990) generally requires at least some knowledge of where an object is, where it has been, and/or where it is going. Because space is so fundamental to reasoning abilities, we would expect even very young infants to reason about object location. Indeed, in a previous study, we found that when given two possible locations of hiding, infants as young as 2.5 months of age could remember where an object had been hidden and were surprised to see it reappear at another location (Wilcox & Nadel, 1993; Wilcox, Rosser, & Nadel, 1993). That is, in a visual search task infants remember the correct location of a hidden object, expect it to maintain its original location in space, and to reappear from that location only (Baillargeon & Graber, 1988; Wilcox et al., 1993; Wilcox & Nadel, 1993). These findings, along with other reports that infants do attend to and reason about location information (Baillargeon, 1986; Baillargeon & DeVos, 1991; Baillargeon et al., 1991), support the view that location information plays a crucial role in early reasoning abilities. Although it seems to be the case that infants do reason about where an object is located in space, the manner in which they represent locational information is not known.

Within a small bounded space there are several possible ways that distance information could be encoded (Rosser, 1994). First, one could use a system based on the amount of distance between object locations. If this were the case, one would have some sense of the dimensions, or metric, of the bounded space. For instance, infants' reasoning about the distance between four locations lying on a plane (A-B-C-D) could be described as $A \rightarrow B < A \rightarrow C < A \rightarrow D$. Although it is possible that infants could also reason about the exact amount of distance between each of the locations, this type of reasoning is not required when discrete locations are provided. Alternatively, one could use a system based on general area. In this case, infants may remember that an object is hidden in one area, and not in another area. However, they would be unsure of the exact location within that area. For example, if an object were hidden in location A, they would expect it to reappear in the vicinity of A, but not necessarily at A. They might even generalize to a nearby location, B. However, they would not expect the object to reappear at locations further away, such as C or D. That is, infants may remember the general area in which an object is located, but they may not have precise information about the location of that object. Although it is unclear what would constitute "general area" for an infant, proximity to the location of hiding would be the most reasonable assumption. When older infants are asked to search for hidden objects, errors are usually made to nearby locations (Bjork & Cummings, 1984; Huttenlocher, Newcombe, & Hollister, 1991; Mangen & Nadel, 1989, 1990). Infants tend to search at or near the location of hiding, and rarely search at distal locations. Finally, infants may use both types of information depending on the nature of the task. The question of interest is

whether infants are capable of representing information about the amount of distance between locations, regardless of how precise this information is, or whether infants simply expect objects to be located in the general area at which they were hidden.

Infants may use information other than distance, however, to remember the location of a hidden object. Coding of spatial location in adults, children, and older infants is systematically influenced by the boundaries of the space (Huttenlocher, Hedges, & Duncan, 1991; Huttenlocher & Newcombe, 1984; Huttenlocher, Newcombe, & Hollister, 1991). Boundaries are important because they can be used as locational markers. If young infants do code spatial location in relation to a boundary, memory would be better for locations that lie near a boundary than for locations that lie internally. Again referring to four locations lying on a plane, infants may be better able to remember the location of an object hidden at A or D, assuming they lie near the edge of a bounded space, than the location of an object hidden at B or C. Use of a coding strategy such as this makes a very different behavioral prediction than use of a coding strategy based on distance or general area information.

The evidence bearing on these issues is ambiguous. In older infants, both distance information and the boundary of the space influences memory for the location of a hidden object. When objects are hidden at one of several discrete locations in a small room, infants 12 to 36 months of age have difficulty remembering the location of hiding (DeLoache, 1984; DeLoache & Brown, 1983; Mangan & Nadel, 1989, 1990). They are dependent on landmarks to code location. In addition, landmarks are helpful only when they are proximal to, or intrinsic to, a location of hiding. This suggests that infants are dependent on direct locational markers to remember where an object is located and do not readily encode location in terms of distance information. Yet, when infants 16 to 24 months of age are asked to find a toy they saw hidden in a sandbox, they are very proficient (Huttenlocher, Newcombe, & Hollister, 1991), even in the absence of locational markers. When search errors occur, they are systematically biased towards the center of the bounded space. Finally, when 9- to 11-month-olds are presented with a five position A-not-B search task they are proficient at remembering the correct location of a hidden object, even on reversal trials (Bjork & Cummings, 1984). When errors are made, they occur at a location next to, or near, the correct location. These data suggest that by 9 months infants are capable of representing the distance between possible locations of hiding and are accurate at doing so. However, because Bjork and Cummings (1984) always hid the object at one of the two end positions, the manner in which boundary information influenced coding of location is unknown. It could be that infants performed well on this search task because the object was always hidden on a boundary which marked the location of the hidden object. If the object was hidden at a central location, a greater number of search errors might have occurred.

The purpose of this study was to investigate infants' use of distance and boundary information when coding discrete locations within a small bounded space. The first question of interest was whether infants would use distance information to remember the exact location of a hidden object or whether they would remember location in terms of general area. The second question of interest was whether boundary information would influence coding, resulting in better memory for the location of an object hidden at a boundary, as compared to an internal location. We used a visual search task similar to one used previously (Wilcox et al., 1993; Wilcox & Nadel, 1993). In the present study, infants watched as an object was hidden at one of four possible locations. After a short delay, the object either reappeared from the location at which it was hidden (possible event) or reappeared from one of the other three locations (impossible event). Because infants look longer at novel or surprising events, longer looking times to an impossible event, as compared to a possible event, are thought to reflect memory for the correct location. In addition, we reasoned that if infants are proficient at coding distance information they would be surprised by the impossible event regardless of where it occurred. Alternatively, if infants code distance in terms of general area, they would be surprised by the reappearance of the object at a distal location (i.e., two to three places from the location of hiding) but not by the reappearance of the object at a proximal location (i.e., one place away from the location of hiding). Greater amounts of movement away from the original location may be easier to detect than small amounts of movement. Finally, if infants are strongly influenced by the boundaries of the space, they would be better at encoding locations near a boundary. That is, impossible events that occur after the object is hidden at an end location would be more surprising than those that occur after the object is hidden at a central location.

METHOD

Subjects

Forty-eight healthy, full-term infants (24 male, 24 female) tested at 6.5 months of age ($M = 6$ months, 24 days; $SD = 7$ days) served as subjects. Infants were recruited from birth announcements in the local newspaper. Parents were contacted by phone and follow-up letters. The majority of subjects were Caucasian and from middle-class families. The mean age of the mothers was 29.8 years (range = 24–37 years). The majority of the mothers had some education past high school (77%) and worked at least part-time outside the home (60%).

Apparatus

The apparatus consisted of a foam core box 46 cm high, 103 cm wide, and 48 cm deep. A schematic representation of the apparatus is presented in Figure 1. The infant sat facing an opening 36 cm high and 103 cm wide. The roof of the apparatus slanted upward, increasing the height of the opening to 46 cm at the back wall. A stage, 38.3 cm deep and 103 cm wide, sloped gently upwards

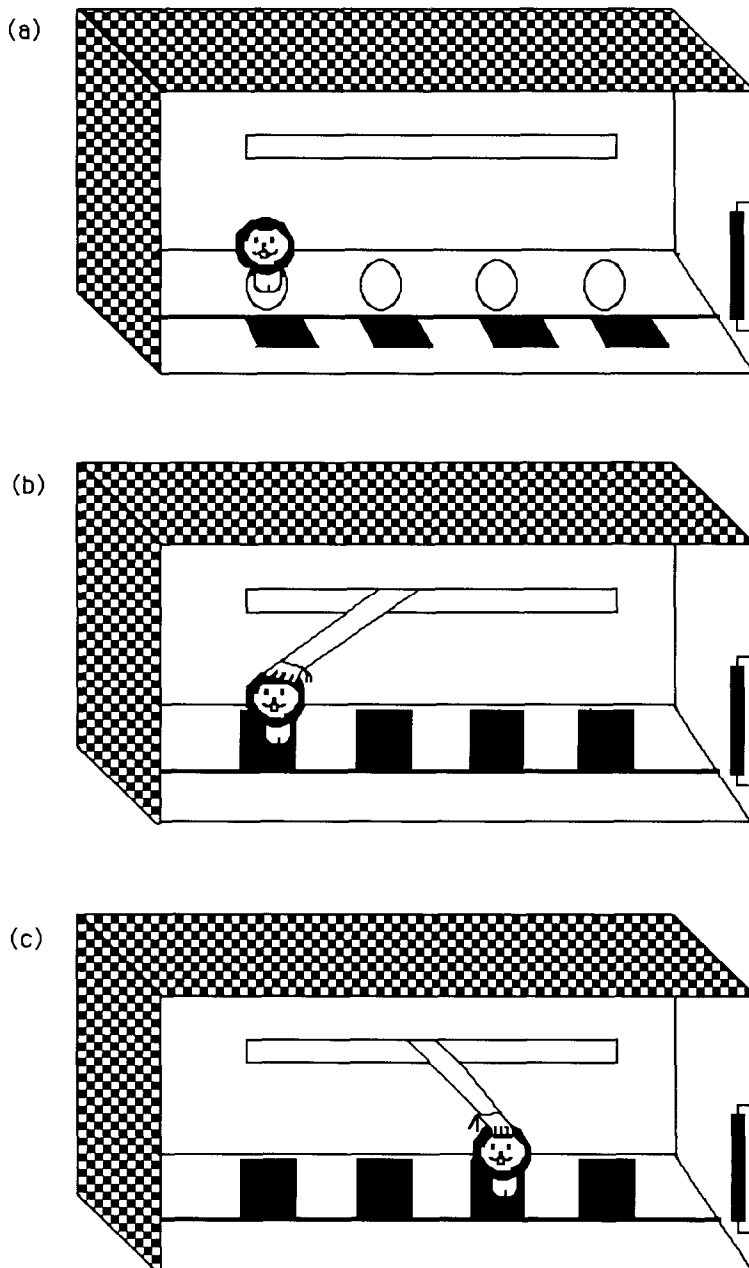


Figure 1. Schematic representation of the four-position visual search task. (A) Familiarization and hiding. The infant views the object sitting at one of the four locations of hiding until reaching familiarization criterion. All four screens are then rotated upward and a short delay (10 s) is imposed. (B) Possible event. The object is retrieved from the correct location of hiding. (C) Impossible event. The object is retrieved from one of the other three locations of hiding.

from the floor of the apparatus to connect with the back wall. The front edge of the stage lay 8 cm from the front opening of the apparatus. The floor, walls, roof, and stage of the apparatus were covered in black felt. Four identical locations of hiding, oval in shape, were marked by a 1 cm wide oval ring made of red felt. Each oval was 6.5 cm wide and 9 cm deep at their widest and deepest points. The back edge of each oval lay 6 cm from the back wall. All four ovals lay 20 cm apart, center to center. The center of each end oval lay 21.5 cm from the side wall. The ovals were, in fact, hinged trap doors that opened under the floor of the apparatus. Objects could be removed from, or placed on, an oval by opening the trap door. In front of each oval stood a cardboard screen covered in yellow felt. The screens were 12.5 cm tall and 11 cm wide and were 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. The screens could be rotated forward to lay flat against the floor of the stage by releasing the metal lever from the magnet. A slit, 8 cm high and 56 cm wide and whose bottom edge lay 16 cm from the floor of the stage, was cut into the back wall of the apparatus to allow for the visible entrance and exit of a gloved hand. The slit was covered with black cloth to mask its existence when not in use. Two 16 cm long tubular lights, each with a 60 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 at its widest point, was the object placed in one of the ovals during the experiment. The lion was securely held to the oval by a small piece of Velcro. The lion squeaked when pressure was applied. During the test events, 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 37 cm from the floor. The parent (or parents) watched the infant on a video screen located behind the apparatus. Occasionally the parent sat next to the infant or the infant sat on the parent's lap. In these cases, the parents were instructed not to interact with their 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. One third (16) of the test sessions were later rescored by an independent second observer. Interobserver reliabilities were calculated with Pearson's r , using looking times from the familiarization and test period of each trial. The mean reliability coefficient was .99.

Each infant saw six test trials with each test trial consisting of: (a) a familiarization period, (b) a delay period, and (c) a test event. One experimenter produced all test trials.

Familiarization Period. Each familiarization period began with the curtain down. When the curtain was raised, the infant saw the lion sitting on one of the four ovals. A gloved hand entered the apparatus through the slit in the back wall (1 s), gently squeaked the lion (3 s), and exited through the back wall (1 s). On the first trial, familiarization ended when the infant looked away from the display 3 times (2 s each time after having looked at it for at least 10 cumulative s) or looked at the display for 30 cumulative s. For all other trials, familiarization ended when the infant: (a) looked away one time for 2 consecutive s after having looked at it for at least 5 cumulative s, or (b) looked at the display for 10 cumulative s. The first familiarization period was longer than the rest because it was the first trial that the infant saw the lion sitting on the oval. The lion was placed in the same location for all of the remaining 5 familiarization trials. The computer signaled the end of the familiarization period, at which time the screens were rotated upward to occlude the four ovals.

Delay Period. Each familiarization period was followed by a 10 s delay interval. During the first 5 s of each delay interval the experimenter either: (a) removed the lion from its original location of hiding and placed it at another location (impossible event) or (b) removed the lion from its original location of hiding and then placed it at the same location again (possible event). Access to each location was gained by releasing the oval trap door. The screens occluded the infants' view of the ovals during this time. The same actions occurred before both impossible and possible events (e.g., opening the trap door, removing the lion, closing the trap door) so noise cues could not be used to distinguish between upcoming events. During the last 5 s of the delay interval the gloved hand, now with a jingle bracelet on, entered the display box from the slit in the back wall. The hand waved from a central location (3 s) and then moved to the screen at which the lion would appear (2 s). The computer ticked like a metronome during the delay interval.

Test Events. Each delay interval was followed by a test period: either a possible or impossible event. In the possible event, the infant saw the hand

Table 1. Conditions for Visual Search Task

Level	Condition 1	Condition 2	Condition 3	Condition 4
A	X — — — — 1 3 2	— X — — 1 — 3 2	— — X — 2 3 — 1	— — — X 2 3 1 —
B	X — — — — 3 2 1	— X — — 3 — 2 1	— — X — 1 2 — 3	— — — X 1 2 3 —
C	X — — — — 2 1 3	— X — — 2 — 1 3	— — X — 3 1 — 2	— — — X 3 1 2 —

Note. Levels A, B, and C within each condition represent counterbalancing. The X indicates the location at which the lion was hidden. The numbers indicate the order of occurrence of impossible events.

retrieve the lion from behind the screen where it was hidden. The lion was squeaked gently after it appeared from behind the screen and was held in front of the screen until the computer signaled the end of the test trial. The impossible event was just like the possible event except that the infant saw the hand retrieve the lion from behind one of the other screens. A schematic representation of possible and impossible test events is presented in Figure 1. The test period ended when the infant looked away for 2 consecutive s after having looked for at least 10 cumulative s or looked for 60 cumulative s without looking away for 2 s. The curtain was then raised and the experimenter prepared for the next trial.

There were four conditions: (1) object was hidden at Place 1 (left-end), (2) object was hidden at Place 2 (left-center), (3) object was hidden at Place 3 (right-center), and (4) object was hidden at Place 4 (right-end). Each infant was tested in only one of these four conditions with 12 infants tested in each condition. Within a condition, the order of locations at which the impossible event occurred was counterbalanced. Conditions and order of impossible events are displayed in Table 1. Each infant saw three pairs of impossible and possible events: a pair of events for each of the three impossible locations of hiding. Half the infants saw the possible event first, the other half saw the impossible event first. Five additional infants were tested but were excluded from the analysis due to fussiness.

DATA ANALYSIS

Rather than analyzing raw scores, a difference percentage score for each test pair [(time to impossible event – time to possible event)/(time to impossible event + time to possible event)] was created. The purpose of these scores was to compare looking times to the impossible and possible event for each individual relative to the total amount of time they spent looking during each test pair. That is, difference percentage scores standardize the difference in looking time to the two

Table 2. Mean (SD) Difference Percentage Scores for Groups 1 and 2

	Location		
Group 1	One place away (inner)	Two places away (inner)	Three places away (end)
	.014 (.264)	-.010 (.254)	.149 (.216)**
Group 2	One place away (end)	One place away (inner)	Two places away (end)
	.116 (.201)**	.006 (.210)	.163 (.243)*

Note. Score is significantly different from zero.

* $p < .05$, two-tailed. ** $p < .01$, two-tailed.

events. Difference percentage scores for test pairs were the unit of measure for all analyses.

Preliminary analysis indicated that infants in Condition 1 performed like infants in Condition 4, and that infants in Condition 2 performed like infants in Condition 3. Conditions 1 and 2 were the mirror image of Conditions 3 and 4, and side of hiding was not expected to influence performance. Consequently, data was collapsed across mirror conditions to form two groups. Group 1 consisted of infants who saw the lion hidden at an end location and Group 2 consisted of infants who saw the lion hidden at an inner location. Preliminary analyses also indicated that order of event (possible or impossible event seen first) did not significantly effect performance. Consequently, data was also collapsed across levels of this factor. Mean difference percentage scores, for each of the two major groups discussed earlier, are presented in Table 2. Raw looking times to the two events are presented in Table 3.

Table 3. Mean (SD) Looking Times to the Possible (P) and Impossible (I) Events for Groups 1 and 2 (in Seconds)

	One Place Away (Inner)		Two Places Away (Inner)		Three Places Away (End)	
	P	I	P	I	P	I
Group 1	17.88	20.31	21.36	20.55	24.36	29.87
	(10.6)	(12.9)	(13.5)	(10.1)	(13.7)	(14.1)
	One Place Away (End)		One Place Away (Inner)		Two Places Away (End)	
	P	I	P	I	P	I
Group 2	19.02	23.92	21.72	21.84	20.41	28.55
	(10.8)	(11.4)	(14.0)	(13.1)	(12.4)	(14.9)

RESULTS

Dunn's procedure for a priori nonorthogonal contrasts (Kirk, 1982) was used to test the effect of distance, general area, and boundary information on coding of location. To generate the appropriate error term for the three comparisons, a one-way analysis of variance (ANOVA) was performed on data from Group 1 and Group 2 separately, with place (number of places away that the impossible event occurred) as the within subject variable. The resulting mean square error term, .055, was used for computation of Dunn's procedure.

To determine if infants looked longer at the impossible, as compared to the possible, test event (i.e., regardless of distance or boundary information), we compared mean difference percentage scores to zero ($M - 0 > 0$). This comparison was significant, $tD = 2.33$, $df = 144$, $t_{crit} = 2.36$, $p < .01$, indicating that in general, infants looked longer at the impossible event. However, examination of the mean difference percentage scores displayed in Table 2 indicates that infants did not look longer at the impossible event on all test pairs.

To determine if infants coded location in terms of general area, we compared mean difference percentage scores for test pairs where the impossible event occurred two or more places away from the original location to test pairs where the impossible event occurred only one place away from where the object was hidden ($M_{2,3} - M_1 > 0$). If infants coded the location of hiding in terms of general area, then they would be surprised to see the object reappear at a distal, but not at a nearby, location. This comparison was not significant, $tD = 1.25$, $df = 72$, $t_{crit} = 2.39$, $p > .01$, indicating that infants did not evidence significantly higher difference percentage scores on test pairs where the impossible event occurred two to three positions away from the original location of hiding than where the impossible event occurred only one position away from the original location of hiding. Memory for the location of hiding was not systematically influenced by distance of the impossible event from the correct location.

Two comparisons clearly illustrate this point. The first is an examination of difference percentage scores for Group 2, one place away, inner position and Group 2, one place away, end position (see Table 2). Infants were surprised to see the object reappear one position away when it occurred at a boundary. They were not surprised by the same event when it occurred at a central location. The second comparison is an examination of difference percentage scores for Group 1, two places away, inner position and Group 2, two places away, end position (see Table 2). Infants were surprised to see the object reappear two positions away, but only when this occurred at an end position. They were not surprised when the same event occurred at a central location. Clearly, the amount of distance of the impossible event from the original location of hiding was not an important factor. These comparisons also indicate that infants did not code location of hiding in terms of the right or left side of space. They were not uniformly surprised by the reappearance of the object on the side opposite its hiding.

To test for the effect of boundary information on location memory, we compared mean difference percentage scores for test pairs where the object was hidden at an end location to mean difference percentage scores for test pairs where the object was hidden at an inner location (M Group 1 - M Group 2 > 0). If infants are better at coding boundary locations than central locations, then infants in Group 1 should perform significantly better than infants in Group 2. This comparison was not significant, $tD = -1.1$, $df = 72$, $t_{crit} = 2.39$, $p > .01$. The mean difference percentage scores for Groups 1 and 2 were similar, indicating that coding of location was not reliably better when the object was hidden at a boundary, rather than at a central, location.

The previous results led us to conclude that neither distance information nor encoding of location in relation to a boundary systematically influenced location memory in this task, at least not in the manner specified. Infants appeared to be influenced by the location at which the object reappeared rather than the location at which it was hidden. They were surprised to see an impossible event occur at a boundary location but were not surprised to see it occur at a central location. An a posteriori analysis using Dunn's procedure was performed to determine if the mean difference percentage scores were significantly greater for test pairs where the impossible event occurred on a boundary rather than at a central location ($M_{end} - M_{inner} > 0$). This comparison was significant, $tD = 3.43$, $df = 72$, $t_{crit} = 2.39$, $p < .01$, indicating that difference percentage scores were significantly better when infants saw an impossible event occur at an end, as compared to an inner, position. Infants were influenced by boundary information but only when it marked the location of an impossible event.

Before accepting this explanation, however, several issues need to be addressed. First, it is possible that position-related preferences in attention during familiarization trials resulted in differential performance during test trials. To test for position preferences, we analyzed looking times for the first familiarization period using a one-way ANOVA, with condition (object placed at left, left-center, right-center, right) as the between subjects variable. Although the effect of condition was not significant, $F(3, 44) = 2.77$, $p = .053$, there was a trend for infants to look longer at the object if it was placed at an inner location (Condition 2: $M = 26.6$, $SD = 5.6$; Condition 3: $M = 26.2$, $SD = 6.0$) than at an outer location (Condition 1: $M = 22.9$, $SD = 6.9$; Condition 4: $M = 20.2$, $SD = 6.4$). It could be argued that because infants tended to spend more time looking at the center positions during the familiarization trials, locational changes away from these positions (e.g., to end positions) would be more readily noticed. However, when hidden at a central location the object did not always change location to an end position. Sometimes it changed location to the other central location. If greater attention to central locations led to better encoding of object location, infants should have been surprised when the object moved to another central, as well as a boundary, position.

Likewise, it is possible that difference percentage scores for locational

changes to an end position were higher than those to a center location because infants developed a preference for end positions over the course of the test session. If so, this would decrease difference percentage scores for movements from end to inner positions and increase difference percentage scores for movements from inner to end positions. To test for this possibility, we compared mean looking times for trials where the possible event occurred at an end position to those where the possible event occurred at an inner position using Studentized *t*. (A comparison of trial related changes were not feasible because the location of the impossible event was counterbalanced across infants and trials.) This comparison was not significant. The infants looked equally long at possible events that occurred at inner ($M = 20.7$, $SD = 12.0$) and end positions ($M = 22.0$, $SD = 11.5$).

Finally, it is possible that the infants were using a variety of different strategies for coding object location. We examined difference percentage scores for each impossible location to determine if most infants were, in fact, surprised to see the impossible event at end locations. In Group 1, the percentage of infants surprised by the reappearance of the object at one (inner), two (inner), and three (outer) positions away was 42%, 54%, and 67%. The further the object reappeared from the correct location of hiding, the more likely the infants were to be surprised by its appearance. In addition, if the object reappeared on the opposite side of space, they were more likely to be surprised than if it reappeared in the same general area. However, only when the object reappeared at the end position were the greatest number of infants surprised by its reappearance. In Group 2, the percentage of infants surprised by the reappearance of the object at one (outer), one (inner), and two (outer) positions away was 75%, 58%, and 75%, respectively. More infants were surprised by the reappearance of the object at an end, rather than an inner, position.

DISCUSSION

The present study extends the findings from our two-position visual research task (Wilcox et al., 1993; Wilcox & Nadel, 1993), but in unexpected ways. We proposed that when given four discrete locations of hiding, infants would code location in one of three ways, each of which would result in a different pattern of looking behavior. First, infants could code location using distance information resulting in surprise at the reappearance of the object at all impossible locations. Alternatively, they could use general area to code location and evidence surprise when the object reappeared at a distal, but not a proximal, location. Finally, infants could code location in relation to a boundary and would be better able to remember locations that lie next to a boundary than locations that lie internally. If using this strategy, infants would be surprised when the object moved away from a boundary, but not an inner, position. Infants in this study failed to use any of these strategies to code location. The reappearance of the object at a new location

did not routinely elicit surprise; infants did not respond to all locational changes. The amount of distance that the object moved from the original location of hiding also did not systematically influence difference percentage scores. For example, sometimes infants were surprised by the reappearance of the object one place away; at other times this was not surprising. Finally, infants were not more likely to notice a locational change away from an end, as compared to an inner, position.

However, there was a distinct pattern to looking behavior. Elevated looking times were determined by the location at which the object reappeared rather than the location at which it was hidden. When an object was *hidden* at a boundary, infants were not necessarily surprised to see it reappear at another location. However, when the object *reappeared* at a boundary, when it should not have, infants were surprised. These results indicate that boundary information does influence infants' representation of spatial location, but in a very different manner than expected.

Although not predicted, the asymmetrical fashion in which the infants used boundary information provides important information about the way in which infants code location. Infants' surprise at seeing an impossible event is taken as an indication that a mismatch between a memory representation and current information has occurred. In this study, the representation that an object was previously at a boundary position, matched with current information that the object is no longer at that location, did not always elicit surprise. Conversely, the representation that the object was not at a boundary position, matched with current information that the object is now at that location, routinely elicited surprise. That is, both boundary information and the presence or absence of the object were important factors in the detection of change in object location. The way in which both factors influenced memory for location was systematic. First, infants were more likely to notice a change that occurred at a boundary. Second, if the change at the boundary involved the appearance of an object in a location that was previously unoccupied, infants were surprised. If the change involved the absence of an object from a location that was previously occupied, they were not surprised.

This interpretation is consistent with several lines of research. First, the importance of boundaries in coding of spatial location has been demonstrated in older infants and children. Children are more accurate at remembering the location of a target, or object, that lay near the edge of a bounded space (Herman & Siegel, 1978; Huttenlocher & Newcombe, 1984; Huttenlocher, Newcombe, & Hollister, 1991). In addition, children's judgments about distance are influenced by the boundaries of a space (Acredelo & Boulter, 1984; Herman & Siegel, 1978). Our current findings indicate that young infants' coding of location is also influenced by boundary information. From an early age, we appear to use boundary information to think about, build representations of, and remember spatial locations.

Second, there are recent findings indicating that infants are more likely to notice a change in a visual stimulus that involves the addition of a part rather than the deletion of a part (Coldren, 1993). For example, infants are more likely to notice a change in a letter stimulus from F to E, than from E to F. Detection of change in the physical appearance, or spatial arrangement, of a visual stimulus appears to depend on the nature of that change. We found that detection of change in the location of an object was also dependent on the nature of the change. The addition (i.e., unexpected reappearance) of an object seems to be more salient than the deletion (i.e., failure to reappear) of an object. When reasoning about the spatial properties of objects, infants often need salient and visible reminders to encourage them to attend to relevant information, such as the height or location of an object, and to use this information once the object is hidden from view (Baillargeon, *in press*). An object failing to reappear at a boundary position, even though it reappears elsewhere in the display, may not be a salient violation of spatial information to an infant. However, an object appearing at a boundary that was previously unoccupied, where the object serves as a visible reminder of the violation and the boundary serves as a locational marker, may be very salient.

In sum, it appears that infants' reasoning about multiple discrete locations is driven by currently viewed information which is used to update short-term representations of space. In addition, updating of location information is better at some locations. When the object reappears at a central location, updating of location information is sketchy, at best. In contrast, when the object reappears at an end location, infants are usually able to determine if the object had been in that location before. We have also suggested that ambiguous updating of central locations and correct updating of locations that lay near a boundary is due to a dependence on locational markers to distinguish between discrete locations in space. However, there may be an alternative explanation for the end-position advantage. Similar position-related differences in performance have been reported in the adult perception literature (e.g., Butler & Currie, 1986; Styles & Allport, 1986). Subjects are more accurate at reporting information about visual stimuli that fall at the end of a visual array and less accurate at reporting information about stimuli that lie at inner positions. One explanation for this phenomenon is that there are limitations in the ability to integrate information from different processing subsystems (i.e., color/location and featural characteristics) for object identification (Styles & Allport, 1986). Our findings could be indicative of similar processing limitations in infants. Infants may be attempting to integrate information about the object itself (i.e., "Is this the same object I saw before or a different object?") with the location of the object (i.e., "Is this the same location or a different location?") during the test event. If so, and the ends-in advantage is due to limitations in the integration of featural and locational information, then a decrease in performance at inner positions would result.

The fact that in this study the infants did not systematically detect changes in

position relative to the original location appears in conflict with other results regarding infants' representation of locational information. Baillargeon and colleagues (Baillargeon, 1986, 1991; Baillargeon et al., 1991; Baillargeon & DeVos, 1991) have found that young infants can remember the relative location of objects and reason about the physical and spatial properties of these objects even when they are occluded. For example, in one set of experiments (Baillargeon, 1986; Baillargeon & DeVos, 1991), infants saw an object (i.e., a toy mouse or a box) placed either in front of, on, or behind a track. The object and the middle portion of the track were then occluded by a screen and the infants saw a toy car roll down the track. At 4 (females) and 6 (males, females) months of age, infants were surprised to see the car reappear from behind the screen when the object was placed on the track. They were not surprised to see the car reappear from behind the screen when the object was placed in front of or behind the track. Infants remembered where the object was located in relation to the toy track and did not expect the toy car to reappear when the track had been blocked. In contrast, in our task infants were not systematically surprised to see the object reappear at another location. Infants did not remember the location of the hidden object relative to the other possible locations in the display.

However, these differences can be explained in terms of information provided in the display. In Baillargeon's (1986) task, each object in the display was unique. Infants needed to remember the functional relation (in front of, on, behind) of one unique object (toy box) from another (track). In our task, infants needed to remember the correct screen that the object was behind in relation to three other identical screens. Apparently, it is much easier for infants to remember the relative location of unique objects than to remember one of four identical locations. These findings are similar to those from search tasks. When a toy is hidden at one of four identical locations in a room, 18-month-old infants have difficulty finding the toy. However, when a toy is hidden in a natural environment (e.g., a room with furniture) where the locational marker is intrinsic to the location of hiding (e.g., under the couch), they perform quite well (DeLoache, 1984; DeLoache & Brown, 1983). Similarly, when asked to place objects at their correct location, young children are best at placing them in relation to a clearly marked boundary or landmark (Herman & Siegel, 1978; Huttenlocher & Newcombe, 1984). Remembering the location of an object within a uniform internal array appears to be more difficult than remembering the location of an object in relation to other unique objects or when locations are clearly marked. One would predict, then, that infants would be able to remember the location of an object in our four position task if locational markers were provided. However, taking into consideration the finding of Huttenlocher, Newcombe, & Hollister (1991), one would also suspect that when asked to reason about the distance between objects on a continuum, rather than when given discrete locations, young infants might be quite proficient at encoding distance information.

The results of our study indicate that infants can remember the location of a

hidden object when four possible locations of hiding are presented, but memory is constrained by at least two factors. First, representation of spatial location is strongly influenced by the boundary of the space. Infants are more likely to notice changes in location to a boundary. The finding that the amount of distance between the location of hiding and where the object reappeared was not an important factor suggests that infants do not represent small bounded spaces in terms of distance. This leaves open the possibility that infants do not reason about distance at all or that under some conditions boundary information is more salient than distance information. Our findings, in conjunction with other current findings (Baillargeon, 1986; Baillargeon et al., 1991; Baillargeon & DeVos, 1991), indicate that the latter is probably true. Within a small bounded space, void of locational markers, boundary information is more salient than distance information. Second, detection of change at a boundary is influenced by the nature of the change. Infants are much more likely to notice a change that involves the presence of an object at a boundary than the absence of an object at a boundary. Updating of location information near a boundary is most efficient when the object is present at the boundary.

REFERENCES

- Acredelo, L.P., & Boulter, L.T. (1984). Effects of hierarchical organization on children's judgments of distance and direction. *Journal of Experimental Child Psychology, 37*, 409-425.
- Baillargeon, R. (1986). Representing the existence and the location of hidden objects: Object permanence in 6- and 8-month-old infants. *Cognition, 23*, 21-41.
- Baillargeon, R. (1987). Object permanence in 3.5- and 4.5-month-old infants. *Developmental Psychology, 23*, 655-664.
- Baillargeon, R. (1991). Reasoning about the height and location of a hidden object in 4.5- and 6.5-month-old infants. *Cognition, 38*, 13-42.
- Baillargeon, R. (in press). A model of physical reasoning in infancy. In C. Rovee-Collier & L. Lipsitt (Eds.), *Advances in infancy research* (Vol. 9). Norwood, NJ: Ablex.
- Baillargeon, R., & DeVos, J. (1991). Object permanence in young infants: Further evidence. *Child Development, 62*, 1127-1246.
- Baillargeon, R., & Graber, M. (1988). Evidence of location memory in 8-month-old infants in a nonsearch AB task. *Developmental Psychology, 24*, 502-511.
- Baillargeon, R., Graber, M., DeVos, J., & Black, J. (1991). Why do young infants fail to search for hidden objects? *Cognition, 36*, 255-284.
- Baillargeon, R., Spelke, E., & Wasserman, S. (1985). Object permanence in 5-month-old infants. *Cognition, 20*, 191-208.
- Bjork, E.L., & Cummings, E.M. (1984). Infant search errors: Stage of concept development or stage of memory development. *Memory and Cognition, 12*, 1-19.
- Butler, B.E., & Currie, A.M. (1986). Attention in the periphery: A new look at lateral masking. *Psychological Research, 48*, 201-209.
- Coldren, J. (1993, March). Asymmetries in 16-week-olds' attention to additions and deletions of distinguishing features. Poster presented at the biennial meeting of the Society for Research in Child Development, New Orleans, LA.
- DeLoache, J. (1984). Oh where, oh where: Memory-based searching by very young children. In C. Sophian (Ed.), *Origins of cognitive skills* (pp. 57-80). Hillsdale, NJ: Erlbaum.

- DeLoache, J., & Brown, A. (1983). Very young children's memory for the location of objects in a large-scale environment. *Child Development, 54*, 888–897.
- Herman, J., & Siegel, A. (1978). The development of cognitive mapping of the large-scale environment. *Journal of Experimental Child Psychology, 26*, 389–406.
- Huttenlocher, J., Hedges, L., & Duncan, S. (1991). Categories and particulars: Prototype effects in estimating spatial location. *Psychological Review, 98*, 352–376.
- Huttenlocher, J., & Newcombe, N. (1984). The child's representation of information about location. In C. Sophian (Ed.), *Origins of cognitive skills* (pp. 81–111). Hillsdale, NJ: Erlbaum.
- Huttenlocher, J., Newcombe, N., & Hollister, E. (1991, March). The coding of spatial location in young children. Paper presented at the biennial meeting of the Society for Research in Child Development, Seattle, WA.
- Kirk, R.E. (1982). *Experimental design* (2nd ed.). Monterey, CA: Brooks/Cole.
- Mangan, P., & Nadel, L. (1989). Spatial memory performance in two-year-old human infants. *Society for Neuroscience Abstracts, 15*, 245.
- Mangan, P., & Nadel, L. (1990, November). Development of spatial memory in the human infant. Paper presented to the Psychonomic Society, New Orleans, LA.
- Rosser, R. (1994). *Cognitive development: Psychological & biological perspectives*. Boston, MA: Allyn & Bacon.
- Spelke, E. (1990). Principles of object perception. *Cognitive Science, 14*, 29–56.
- Spelke, E., Breinlinger, K., Macomber, J., & Jacobsen, K. (1992). Origins of knowledge. *Psychological Review, 99*, 605–632.
- Styles, E.A., & Allport, D.A. (1986). Perceptual integration of identity, location, and colour. *Psychological Research, 48*, 189–200.
- Wilcox, T., & Nadel, L. (1993, March). Location memory in infants 2.5–6.5 months of age. Poster presented at the biennial meeting of the Society for Research in Child Development, New Orleans, LA.
- Wilcox, T., Rosser, R., & Nadel, L. (1993). *Location memory in young infants*. Manuscript submitted for publication.