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Evidence of Location Memory in 8-Month-Old Infants in a Nonsearch AB Task

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Recent studies have shown that when an object is hidden in a location A and then in a location B, 8-month-old infants tend to search in A if forced to wait 3 s before retrieving the object, and to search randomly in A or B if forced to wait 6 s before retrieving the object (e.g., Diamond, 1985). A nonsearch method was devised to examine 8-month-olds' ability to remember the location of a hidden object. The infants saw an object standing on one of two placemats located on either side of the midline. Next, screens were pushed in front of the placemats, hiding the object from view. After 15 s, a hand reached behind one of the screens and reappeared holding the object. The infants looked reliably longer when the hand retrieved the object from behind the "wrong" as opposed to the "right" screen (where the object was actually hidden). This result suggests that the infants (a) remembered the object's location during the 15-s delay and (b) were surprised to see the object retrieved from behind the right (left) screen when they had last seen it on the left (right) placemat. These results indicate that 8-month-old infants' ability to remember the location of a hidden object is far better than their performance in the AB search task suggests. As such, the present results cast serious doubts on accounts that attribute infants' perseverative and/or random search errors to limited memory mechanisms.

Piaget (1936/1954) noted that when young infants begin to search for hidden objects, at about 9 months of age, they often search in the wrong location. Specifically, if an object is hidden in a location A and then in a location B, they tend to search for it in A, where they first found it. Piaget took these errors to indicate that although infants endow the hidden object with permanence, as evidenced by their willingness to search for it, this permanence is still incomplete. Infants do not conceive of the object as an independent entity whose displacements are regulated by physical laws, but as the extension, or the product, of their action: When the object disappears at B, they search for it at A because they expect that by reproducing their action at A they will again produce the object. According to Piaget, the object is " 'at disposal' without being found anywhere from a spatial point of view. It remains what an occult spirit is to the magician: ready to return if one catches it successfully but obeying no objective law" (p. 13). It is not until infants are about 12 months of age, Piaget maintained, that they come to view the hidden object as a separate entity whose location is independent of their own perceptions and actions.

Over the past three decades, Piaget's observations have been tested by many researchers (see Bremner, 1985; Harris, in press; Sophian, 1984; Wellman, 1985; Wellman, Cross, & Bartsch, 1987, for recent reviews). These investigators have uncovered several facts about infants' perseverative errors that are inconsistent with Piaget's account. In particular, it seems that perseverative errors rarely occur when infants are permitted to search immediately after the object is hidden at B; errors occur only when infants are forced to wait before they search, and the older the infants, the longer the delay necessary to produce errors (e.g., Diamond, 1985; Fox, Kagan, & Weiskopf, 1979; Gratch, Appel, Evans, Lecompte, & Wright, 1974; Harris, 1973; Miller, Cohen, & Hill, 1970; Wellman et al., 1987). Thus, according to a recent longitudinal study (Diamond, 1985), the delay needed to elicit AB errors increases at a mean rate of 2 s per month, from less than 2 s at 7.5 months to over 10 s by 12 months. There is no obvious way in which Piaget's theory can explain these findings.

In recent years, many interpretations have been proposed for infants' AB errors (e.g., Bjork & Cummings, 1984; Diamond, 1985; Harris, in press; Kagan, 1974; Schacter, Moscovitch, Tulving, McLachlan, & Freedman, 1986; Sophian & Wellman, 1983; Wellman et al., 1987). For example, Kagan (1974) speculated that these errors reflect the limits of infants' recall memory, with increases in the delay necessary to elicit AB errors corresponding to increases in infants' retention capacity. However, there are several reasons to question this proposal. One is that researchers have reported successful performances on A trials with delays identical to those that lead to perseverative errors on B trials (e.g., Diamond, 1985; Webb, Massar, & Nadolny, 1972; Wellman et al., 1987). Another reason is that there is growing evidence from analyses of parents' diaries (e.g., Ashmead & Perlmutter, 1980) as well as from experimental investigations of imitation (e.g., Meltzoff, 1988) and operant conditioning (e.g., Rovee-Collier & Hayne, 1987) that infants can recall information after intervals considerably longer than those

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used in the AB search task. For example, Meltzoff (1988) found that 9-month-old infants could imitate actions that they had observed an experimenter model 24 hours earlier.

These findings suggest that infants err on B trials not simply because a delay is imposed between hiding and search (because infants perform successfully in different circumstances with comparable or even longer delays), but also because the object is hidden in a new location. Why does the presence of these two factors—imposition of a delay and shift to a new location—result in infants' committing search errors? One account assumes that, during the delay between hiding and search, infants' B representation is rapidly supplanted by the A representation formed on the previous trial because of an extreme sensitivity to proactive interference (e.g., Harris, 1973; Schacter & Moscovitch, 1983). According to this view, as they grow older, infants become able to withstand longer and longer delays before they forget the object's location (i.e., before the B representation is superseded by the A representation). Another account maintains that both the A and the B representations remain available in memory. However, when deciding where the object is located before engaging in search, infants tend to choose the prior A location over the current B location because of an inadequate selectivity rule (e.g., Sophian & Wellman, 1983), because of a mistaken attempt to infer the object's current location from its prior location (e.g., Wellman et al., 1987), or because of an undue reliance on long-term landmark information (e.g., Harris, in press). In each case it is assumed that infants are more likely to choose the correct B location when there is no delay between hiding and search and that, with increasing age, infants choose correctly over increasingly long delays.

The two accounts just mentioned suppose that infants search at A on B trials because they believe the object to be at A; infants' memory of the object's hiding at B is assumed to be either forgotten or overlooked. Diamond (1985) recently put forth a very different interpretation of infants' AB errors. She proposed that infants search at A on B trials not because they misremember the object's location but because they cannot inhibit the previously reinforced response of searching at A, possibly because of poor neurological control (e.g., Diamond, 1987; Diamond & Goldman-Rakic, 1983, 1985). Diamond (1985) reported anecdotal evidence supporting her account. In an AB task involving wells, Diamond noted that on B trials, the infants would often uncover the A well and then go directly to the B well, without even glancing inside the A well, as though they knew such an action would be pointless. Furthermore, the infants would occasionally reach toward the A well while staring fixedly at the B well, as though they knew where the object was hidden but could not override their tendency to search at A. Several other investigators have made similar observations (e.g., DeLoache, personal communication; Gratch & Schatz, 1984).

Diamond's (1985) account does not deny that memory limitations contribute to infants' search errors. However, these limitations are assumed to be responsible for infants' *random* rather than perseverative search errors. Diamond found that increasing by 2 to 3 s the delay at which infants produce perseverative errors results in random searches, even on A trials.[1] Thus, Diamond is arguing that two factors need to be considered to explain infants' search responses: (a) their ability to remember the location of the hidden object and (b) their ability to inhibit responses that are no longer appropriate—or, more positively, to plan and implement responses that are context-appropriate. When there is no delay, infants have no difficulty remembering the object's location and using this information to plan their search action. With longer delays, infants still recall the object's location but are no longer able to use this information to guide their search; their last (successful) response now dominates the planning of their next response, resulting in perseverative errors. Finally, with even longer delays, infants forget the location of the object, leading to chance responding.

How can one decide between the accounts described earlier (e.g., Harris, in press; Schacter & Moscovitch, 1983; Sophian & Wellman, 1983; Wellman et al., 1987), which attribute infants' perseverative and, presumably, random search errors to inadequate memory mechanisms, and Diamond's (1985) hybrid account, which holds that infants' perseverative errors reflect action limitations, and infants' random errors, memory limitations? One approach would be to examine infants' location memory using a nonsearch task. Diamond's account predicts that, when given a task that does not require manual search, infants should exhibit accurate location memory at delays that elicit perseverative errors and poor location memory at delays that produce random errors. In contrast, the memory accounts predict that infants should evidence poor location memory at delays associated with either perseverative or random errors.

To test these predictions, we first conducted a pilot experiment with 7- and 8-month-old infants using a method adapted from Baillargeon (1986). The infants sat in front of two screens placed a short distance apart. A large box was hidden behind one of the screens. To the left of the screens was a long, inclined ramp. The infants saw two test events. In both events, the screens were raised (revealing the box) and lowered, and a toy car rolled down the ramp, passed behind the screens, and exited the apparatus to the right; this sequence was repeated until the trial ended. The only difference between the two events was in the location of the box. In one event (possible event), the box stood in *back* of the car's tracks; in the other (impossible event), the box stood on *top* of the car's tracks, blocking its path. For half of the infants, the box was hidden on top of the tracks behind the right screen (impossible event) and in back of the tracks behind the left screen (possible event); for the other infants, the box was hidden on top of the tracks behind the left screen (impossible event) and in back of the tracks behind the right screen (possible event). The infants saw the impossible and the possible events on alternate trials (order was counterbalanced) until they had completed four pairs of test trials.

This experiment tested whether the infants (a) remembered the location of the box after the screens were lowered and (b) were surprised to see the car continue its trajectory when the box stood in its path. The delay between the lowering of the screens and the emergence of the car from behind the right screen (i.e., the delay during which the infants had to remember the box's location in order to show surprise at the impossible event) was systematically varied and was either 3 or 6 s. We

[1] This result does not mean that infants who were given only A trials would perform at chance if forced to wait for a period corresponding to the delay at which they produce perseverative errors plus 2 to 3 s. This result only applies to A trials administered in the context of (a relatively long series of) A and B trials. To our knowledge, no one has ever investigated infants' location memory using A trials alone.

selected these values because evidence collected using the standard AB task indicates that 8-month-old infants typically search perseveratively with a delay of 3 s (e.g., Butterworth, 1977; Diamond, 1985; Fox et al., 1979; Gratch & Landers, 1971; Wellman et al., 1987) and search randomly with a delay of 6 s (Diamond, 1985). Diamond's (1985) account predicted that the infants in the 3-s but not the 6-s condition would remember the location of the occluded box on each trial. In contrast, the memory accounts (e.g., Harris, in press; Schacter & Moscovitch, 1983; Sophian & Wellman, 1983; Wellman et al., 1987) predicted that neither the infants in the 3-s condition nor those in the 6-s condition would remember the box's location across trials.

Preliminary analyses revealed no reliable differences between the responses of the infants in the 3-s and the 6-s conditions. The infants looked reliably longer (a) when the box was hidden on top as opposed to in back of the tracks and (b) when the box was hidden behind the right as opposed to the left screen. Furthermore, the infants showed the same patterns of looking on all four pairs of test trials. These results suggested that the infants (a) registered the top/back and the left/right location of the box on each trial; (b) remembered this location after the box was occluded; and (c) were surprised to see the car pursue its trajectory when the box was in its path.[2]

The results of our pilot experiment indicated that both the infants in the 3-s and in the 6-s conditions remembered the location of the occluded box on each trial. These results were inconsistent with the predictions derived from the memory accounts (e.g., Harris, in press; Schacter & Moscovitch, 1983; Sophian & Wellman, 1983; Wellman et al., 1987) and only partly consistent with the predictions derived from Diamond's (1985) account. In essence, the results cast doubts on all attempts to explain infants' perseverative and/or random search errors in terms of limited memory mechanisms. Instead, the findings suggested that one should consider the *interaction of memory and action* (how otherwise adequate memory systems are disrupted when actions are required) to account for infants' search errors.

Experiment 1

The results of our pilot experiment suggested that, when given a task that does not require manual search, 7- and 8-month-old infants remember trial-to-trial changes in an object's location over delays as long as, and perhaps considerably longer than, those that elicit errors in the AB search task. Experiment 1 attempted to confirm and extend these results. It differed from the pilot experiment in two important ways. First, the task used was simpler than the car task used in the pilot experiment and provided a more direct test of infants' ability to remember behind which of two screens an object was hidden. Second, a delay of 15 s was used. Twelve-month-old infants typically search randomly after a delay of this duration (e.g., Diamond, 1985). We reasoned that evidence that 7- and 8-month-old infants could keep track of changes in an object's location over such a delay would give strong support to the suggestion that infants err in the AB task not simply because of memory limitations but because of difficulties linked to the interaction of memory and action.

The infants in the experiment watched two test events. At the start of each event, the infants saw an object standing on one of two identical placemats located on either side of the infants' midline. After 3 s, identical screens were slid in front of the placemats, hiding the object from the infants' view. Next, a human hand, wearing a long silver glove and a bracelet of jingle bells, entered the apparatus through an opening in the right wall and "tiptoed" back and forth in the area between the right wall and the right screen. After frolicking in this fashion for 15 s, the hand reached behind the right screen and came out holding the object, shaking it gently until the end of the trial. The only difference between the two test events was in the location of the object at the start of the trial. In one event (possible event), the object stood on the right placemat; in the other (impossible event), the object stood on the left placemat, and thus should not have been retrieved from behind the right screen (see Figure 1).

Our reasoning was as follows. If the infants remembered the object's location during the 15 s in which the hand tiptoed back and forth, then they should be surprised in the impossible event to see the object retrieved from behind the right screen when they had last seen it occupying the left placemat. Because infants' surprise at an event typically manifests itself by prolonged attention to the event, the infants should look longer at the impossible than at the possible event. On the other hand, if the infants did not remember whether the object stood on the left or the right placemat, then they should look equally at the two test events because neither event would seem surprising.

Method

Subjects

Subjects were 24 full-term infants ranging in age from 7 months, 2 days to 8 months, 15 days (M = 7 months, 20 days). One other infant was eliminated from the experiment because of fussiness. The infants' names in this experiment and in the subsequent experiment were obtained from birth announcements in a local newspaper. Parents were contacted by letters and follow-up phone calls. They were offered reimbursement for their transportation expenses but were not compensated for their participation.

Apparatus

The apparatus consisted of a wooden cubicle 191 cm high, 100.5 cm wide, and 40 cm deep. The infant faced an opening 43 cm high and 94 cm wide in the front wall of the apparatus. The floor of the apparatus was painted yellow, the back wall was painted green, and the side walls were covered with a patterned contact paper.

Two identical red plastic placemats, each 9.5 cm wide and 11.5 cm long, lay 21.5 cm apart (edge-to-edge) at a distance of 6 cm from the back wall. The left placemat was 32 cm from the left wall, and the right

[2] We collected these data for seventy-two 7- to 8-month-olds (M = 7 months, 23 days). Planned comparisons showed that the infants looked reliably longer when the box was hidden (a) on top (M = 25.9) as opposed to in back (M = 23.1) of the tracks, $F(1, 450) = 10.30$, $p < .002$, and (b) behind the right (M = 25.6) as opposed to the left (M = 23.4) screen, $F(1, 450) = 6.08$, $p < .02$. (Researchers who study perceptual and cognitive development have often noted that infants tend to look longer at objects and events presented to the right rather than to the left of the midline, e.g., Banks, personal communication, March 1986; Cohen, 1972; Kinsbourne & Hiscock, 1983).

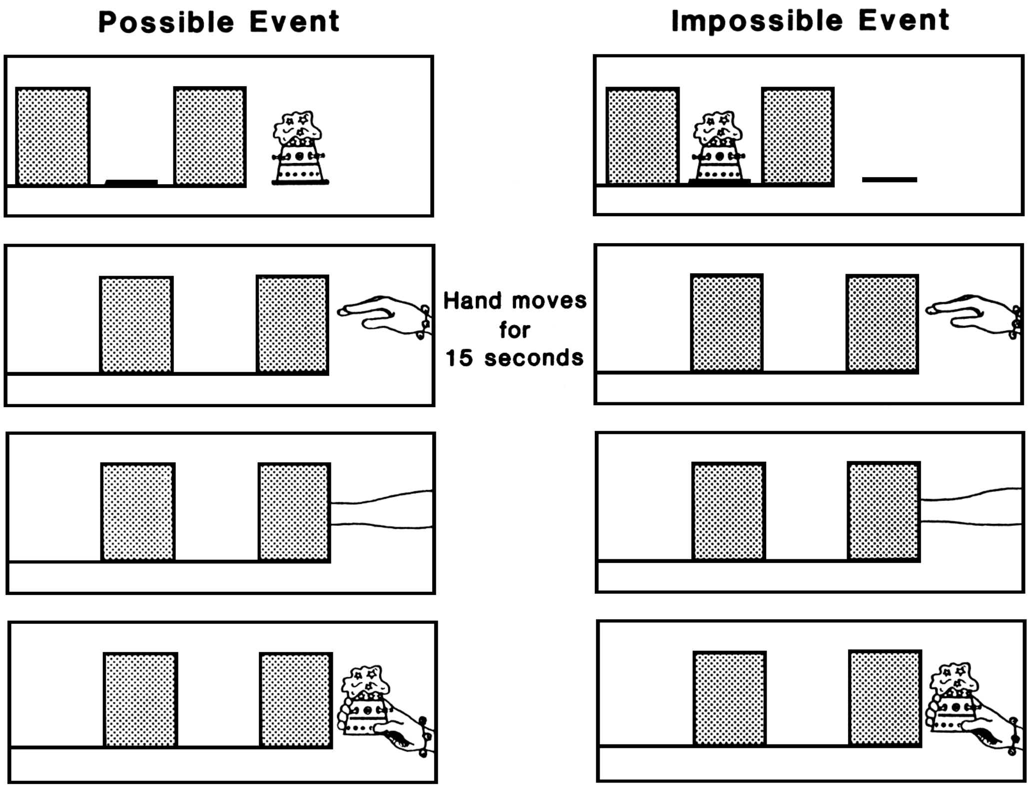

Figure 1. Schematic representation of the test events shown to the infants in Experiment 1.

placemat was 28 cm from the right wall. Two identical purple screens, each 17.5 cm high and 13 cm wide and made of thick cardboard, stood 2 cm in front of the placemats. The left screen was 31.5 cm from the left wall, and the right screen was 27.5 cm from the right wall. A piece of purple cardboard 2 cm high and 15.5 cm wide connected the lower-right corner of the left screen to the lower-left corner of the right screen. The screens could be slid toward the left wall (to reveal the placemats) by means of a yellow handle 1.25 cm high and 75 cm long. The right-end portion of the handle was glued to the back of the cardboard piece connecting the screens; the left-end portion fit between two yellow runners, each 1.25 cm high and 31 cm long, and protruded through the left wall of the apparatus.

The object that was placed on the left or right placemat during the experiment was an inverted white styrofoam cup decorated with dots, stars, and pushpins. The top of the cup was covered with white cotton balls also decorated with stars. With its decorations, the cup was 12 cm high and 8.5 cm in diameter at its widest point. In the impossible test event, a second, identical object was placed on a cardboard ledge behind the right screen. This ledge was 10.5 cm wide and 10.5 cm long and lay on the floor of the apparatus, over the right placemat. Whether on the ledge or on the placemat, the object always stood about 3.5 cm behind the screen.[3] In the possible test event, the ledge was folded up against the back of the right screen and held in place by a strip of velcro.

During the test events, a human hand wearing a silver spandex glove and a bracelet of 5 jingle bells entered the apparatus through an opening 15 cm high and 15 cm wide in the right wall, 0.5 cm above the floor of the apparatus. The glove was 70 cm long and thus covered both the (right) hand and arm of the experimenter.

The infant was tested in a brightly lit room. Four lights (each with a 40-W lightbulb) were attached to the back and side walls of the apparatus to provide additional light. The lights were arranged so as to eliminate tell-tale shadows. Two wooden frames, each 183 cm high and 70 cm wide and covered with blue fabric, stood at an angle on either side of the apparatus. These frames isolated the infant from the test room. A muslin-covered frame 61 cm high and 94 cm wide was lowered in front of the opening in the front wall of the apparatus between trials.

Events

Two experimenters worked in concert to produce the events. The first wore the silver glove and manipulated the object; the second operated the screens.

Impossible test event. The ledge at the back of the right screen lay flat throughout this event and supported one of the objects.

At the beginning of the event, the left screen stood to the left of the left placemat, and the right screen stood to the left of the right placemat. The two placemats and the object standing on the left placemat were clearly visible. After the computer signaled that the infant had looked at the display for 3 cumulative seconds, the second experimenter slid the screens in front of the placemats, taking about 1 s to complete this movement. Next, the first experimenter inserted her right hand (wearing the silver glove and bracelet of jingle bells) into the opening in the right wall of the apparatus. Her hand tiptoed from the wall to the right screen, tiptoed back from the screen to the wall, and finally tiptoed forward once more from the wall to the screen. The first experimenter took about 5 s to tiptoe the distance between the wall and the screen in each direction, resulting in a total tiptoe time of approximately 15 s. At the end of these 15 s, the first experimenter (whose hand was then next to the right screen) reached behind the right screen and came out holding

[3] The reader may be concerned that the infants heard the noise made by the ledge rubbing against the floor of the apparatus when the screens were pushed in front of the placemats. This noise was very faint, however, and could not be heard over the much louder noise made by the wooden handle of the screens when pushed against its wooden runners.

the object, taking about 2 s to complete these actions. She then waved the object gently until the computer signaled that the trial had ended (see below). During the last 5 s before the hand reached behind the screen, the second experimenter shook a rattle behind the right half of the apparatus to ensure that the infant was attending to the hand. At the end of the trial, the second experimenter lowered the curtain in front of the opening in the front wall of the apparatus.

To help the experimenters adhere to the schedule just described, a metronome clicked once per second throughout the experiment.

Possible test event. This event was identical to the impossible event except that the ledge at the back of the right screen was folded up, only one object was used, and this object stood on the *right* placemat until it was retrieved by the hand.

Procedure

The infant sat on his or her parent's lap in front of the apparatus and faced the area between the screens. The infant's head was approximately 62 cm from the screens. Prior to the start of the experiment, each infant was allowed to inspect the object, which was held by the first experimenter in her gloved right hand. The parent was asked not to interact with the infant during the experiment. At the beginning of the test trials, the parent was instructed to close his or her eyes.

The infant's looking behavior was monitored by two observers who viewed the infant through small peepholes in the cloth-covered frames on either side of the apparatus. The observers could not see on which placemat (left or right) the object was placed and they did not know the order in which the events were presented. Each observer held a button box linked to a MICRO/PDP-11 computer and depressed the button when the infant attended to the events. Interobserver agreement on each trial was computed on the basis of the number of seconds that the two observers agreed on the direction of the infant's gaze out of the total number of seconds that the trial lasted (disagreements of less than 0.1 s were ignored). Agreement in this experiment and in the subsequent experiment averaged 93% (or more) per trial per infant. The looking times recorded by the primary observer were used to determine the end of the trials (see below).

At the beginning of the experiment, each infant received two familiarization trials to acquaint him or her with the two possible locations of the object. The two placemats remained visible throughout these trials. In one trial, the object stood on the left placemat; in the other, it stood on the right placemat. The hand did not enter the apparatus during these trials. Half of the infants saw the object on the left placemat first, and half saw the object on the right placemat first. Each trial ended when the infant (a) looked away from the display for 2 consecutive seconds after having looked at it for at least 5 cumulative seconds or (b) looked at the display for 30 cumulative seconds without looking away for 2 consecutive seconds.

When these trials were completed, each infant saw the impossible and the possible events described above. The infants saw the two events on alternate trials until they had completed three pairs of test trials. The infants who saw the object on the left placemat in their first familiarization trial saw the impossible event first, and the infants who saw the object on the right placemat in their first familiarization trial saw the possible event first. Each trial ended when the infant (a) looked away from the event for 2 consecutive seconds after having looked at it for at least 18 s (beginning at the end of the 3-s pretrial, when the screens were pushed in front of the placemats) or (b) looked at the event for 60 cumulative seconds (again, beginning after the 3-s pretrial) without looking away for 2 consecutive seconds. The 18-s value helped ensure that the infants had sufficient information to distinguish the impossible and the possible events.

Seven of the 24 infants in the experiment contributed only two pairs of test trials to the analyses, 4 because of fussiness, 2 because of procedural error, and 1 because the parent asked to terminate the session. All infants were included in the data analyses, whether or not they contributed the full complement of three pairs of test trials.

Results

We analyzed the infants' looking times using a 2×3 mixed model analysis of variance (ANOVA) with Test Pair (first, second, or third pair of test trials) and Event (impossible or possible event) as the within-subjects factors. Because the design was unbalanced, we used the SAS GLM procedure to compute the ANOVA (SAS Institute, 1985). The main effect of event was not significant, $F(1, 101) = 2.75$, $p > .10$, suggesting that the infants tended to look equally at the impossible ($M = 41.0$, $SE = 1.8$) and the possible ($M = 38.1$, $SE = 1.6$) events. The only significant effect was that of test pair, $F(2, 101) = 13.56$, $p = .0001$, indicating that the infants looked reliably less as the experiment progressed.

Age Effects

Examination of the data suggested that the pattern revealed by the ANOVA (statistically equal looking times to the impossible and the possible events) represented the average of two distinct looking patterns. Specifically, it appeared that the older infants in Experiment 1 tended to look longer at the impossible than at the possible event, whereas the younger infants tended to look equally at the two events.

To explore this issue, the infants were divided into two age groups: an older group of 12 infants ranging in age from 7 months, 21 days to 8 months, 15 days (M = 8 months, 1 day), and a younger group of 12 infants ranging in age from 7 months, 2 days to 7 months, 18 days (M = 7 months, 10 days). Half of the infants in each age group saw the impossible event first, and half saw the possible event first.

Figure 2 presents the difference in the older and the younger infants' mean looking times to the impossible and the possible events. It can be seen that most of the older infants, but few of the younger infants, looked longer at the impossible event.

We analyzed these data using a $2 \times 3 \times 2$ mixed model ANOVA with Age (older and younger age groups) as the between-subjects factor and with Test Pair and Event as the within-subjects factors. As before, the analysis yielded a reliable main effect of Test Pair, $F(2, 96) = 15.36$, $p = .0001$. There was also a reliable main effect of Event, $F(1, 96) = 4.10$, $p < .05$, and a reliable Age × Event interaction, $F(1, 96) = 8.34$, $p < .005$. Follow-up comparisons indicated that the older infants looked reliably longer at the impossible ($M = 45.9$, $SE = 2.5$) than at the possible ($M = 38.0$, $SE = 2.3$) event, $F(1, 96) = 9.44$, $p < .01$, whereas the younger infants tended to look equally at the two events, $F(1, 96) = 0.47$ (impossible event: $M = 36.6$, $SE = 2.4$; possible event: $M = 38.3$, $SE = 2.3$). The interactions involving Test Pair and Event were not reliable, all $Fs < 2.72$, indicating that the looking pattern shown by each group of infants did not differ significantly across the three test pairs.

The next question of interest was whether the older infants' reliably longer looks at the impossible event stemmed from their looking longer (a) while the hand was tiptoeing back and forth, (b) while the hand was waving the object, or (c) both. Analysis of the computer record of the infants' responses during each trial indicated that the infants' mean looking times during

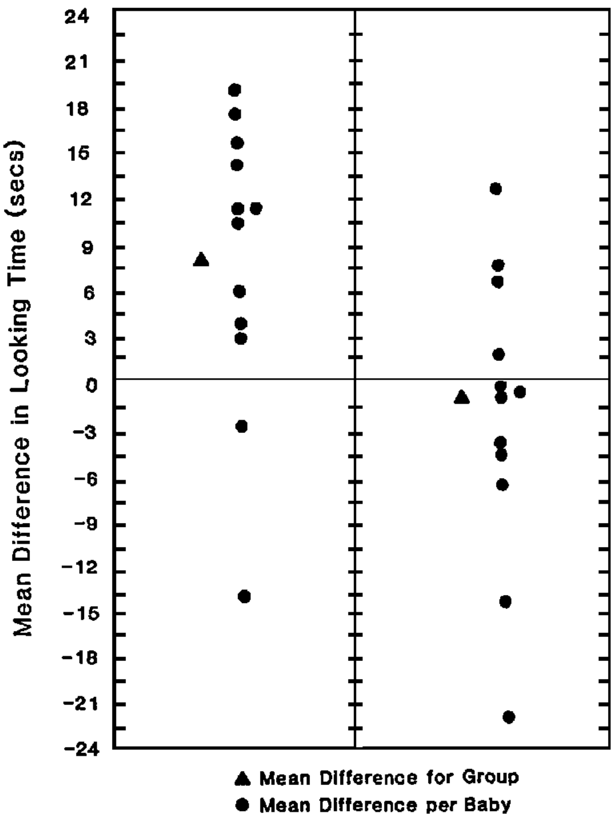

Figure 2. Difference in the mean looking times of the older (left panel) and younger (right panel) infants in Experiment 1 to the impossible and the possible events. (Each dot represents an individual subject. A positive score signifies a longer mean looking time at the impossible than at the possible event; a negative score, in contrast, signifies a longer mean looking time at the possible event.)

the first 15 s of the trials (while the hand was tiptoeing) were 13.6 s (SE = 0.5) and 13.3 s (SE = 0.5) for the impossible and possible events, respectively, $F(1, 45) = 0.06$. The infants' mean looking times after the initial 15 s of the trials (while the hand was shaking the object) were 32.3 s (SE = 2.5) and 24.7 s (SE = 2.1) for the impossible and possible events, respectively, $F(1, 45) = 10.08$, $p < .003$. These results indicated that the infants looked reliably longer at the impossible event only *after* the hand reached behind the right screen to retrieve the object.[4]

Discussion

The 8-month-old infants in Experiment 1 looked reliably longer at the impossible than at the possible event on all three pairs of test trials. These results suggest that the infants (a) registered the object's location at the start of each trial; (b) remembered this location during the 15 s that the hand tiptoed back and forth; and (c) were surprised, after seeing the object on the left placemat, to see it retrieved from behind the right screen.

These results are important in that they suggest that 8-month-old infants can remember trial-to-trial changes in an object's hiding place over delays considerably longer than those associated with search errors in the standard AB task. Recall that 8-month-old infants typically produce perseverative errors with a 3-s delay and random errors, on A as well as on B trials, with a 6-s delay (e.g., Butterworth, 1977; Diamond, 1985; Fox et al., 1979; Gratch & Landers, 1971; Wellman et al., 1987). In marked contrast, the 8-month-old infants in the present experiment seemed to have no difficulty dealing with the 15-s delay embedded in the task. This finding calls into question accounts that attribute infants' perseverative and/or random search errors to inadequate memory mechanisms (e.g., Diamond, 1985; Harris, in press; Schacter & Moscovitch, 1983; Sophian & Wellman, 1983; Wellman et al., 1987). As with the results of the pilot experiment, the present results suggest that 8-month-old infants do possess the memory resources needed to remember an object's new location over a short delay, but only demonstrate these resources in tasks that do not require manual action.

Could there be another explanation for the results of Experiment 1, and, more specifically, for the 8-month-olds' longer looking at the impossible event? It is difficult to think of an alternative interpretation that attributes *no* location memory to the infants. The impossible and possible events were identical except for the location of the object (visible for 3 s) at the start of the events. If the infants had forgotten this location soon after the object was hidden, they would have had no reason to look longer at the impossible event.[5]

However, one could propose an alternative interpretation for our claim that the infants looked longer at the impossible test event because they were surprised, after seeing the object on the left placemat, to see it found behind the right screen. Specifically, one might argue that the infants remembered the object's location after the screens were pushed in front of the placemats but looked longer at the impossible event simply because they happened to prefer the left over the right location for the object. There are several reasons to doubt this explanation. First, researchers usually report preferences in infants for objects presented to the right rather than to the left of the midline (e.g., Cohen, 1972; Kinsbourne & Hiscock, 1983). Second, it is

[4] The younger infants' mean looking times during the first 15 s of the test trials (while the hand tiptoed back and forth) were 14.1 s (SE = 0.3) and 13.6 s (SE = 0.5) for the impossible and possible events, respectively, $F(1, 51) = 1.19$, $p > .05$. The infants' mean looking times after the initial 15 s of the trials (while the hand was shaking the object) were 22.5 s (SE = 2.3) and 24.7 s (SE = 2.3) for the impossible and possible events, respectively, $F(1, 51) = 0.57$.

[5] Another possible interpretation for the results is that the observers could guess from the direction of the infants' looks at the start of each trial whether the object stood on the left or on the right placemat and, hence, whether the infants saw the impossible or the possible event during the trial. There are, however, two reasons to doubt this interpretation. The first is that only the older infants in Experiment 1 looked longer at the impossible than at the possible event. If the observers were biased, it is difficult to understand why they would have been biased with the older infants only. The second has to do with guesses made by the observers at the end of each trial as to whether the infants had seen the impossible or possible event during the trial. If the infants' looks at the beginning of each trial gave the observers excellent information about the location of the object and, hence, the nature of the event shown during the trial, these guesses would have been highly accurate. This was far from being the case. For example, after the first test pair, the two observers guessed the order in which the impossible and possible events had been presented for only 7 (4 younger and 3 older) of the 24 infants in the experiment.

difficult at a logical level to understand why a preference for the object in the left location would have led the infants to look longer at an event occurring near the right location (the more so when one considers that this event involved the retrieval and manipulation of the object, signifying, presumably, that the object was no longer occupying the favored left location). Third, analysis of the older infants' looking times during the familiarization trials indicated that they tended to look equally when the object was on the left (M = 14.6, SE = 2.8) and right (M = 12.9, SE = 2.5) placemats, $F(1, 11)$ = 0.44; similar results were obtained with the younger infants (left placemat: M = 13.1, SE = 2.2; right placemat: M = 11.7, SE = 1.9), $F(1, 11)$ = 0.34. It is unlikely that a preference for the object's left location would have emerged during the test trials in the older but not in the younger infants (recall that the younger infants looked equally at the impossible and the possible events; interpretations of this finding are considered in the General Discussion). Finally, observers occasionally described reactions consistent with the claim that the infants were surprised in the impossible event when the object was retrieved from behind the "wrong" screen. These reactions included: puzzled looks back and forth between the object and the left screen, startled looks, knitted brows, and excited gestures such as arm waving (reports of similar reactions to the possible event were rare).

For all these reasons, it seemed highly unlikely that the older infants in Experiment 1 looked longer at the impossible event because they found the left placemat a more interesting location for the object than the right placemat. In order to completely rule out this alternative interpretation, however, we tested a second group of 8-month-old infants using the same method as in Experiment 1 with one important exception: The hand entered the apparatus through an opening in the *left* wall and reached behind the *left* screen to find the object. Thus, the position of the object during the possible (left screen) and impossible (right screen) events was reversed.

We reasoned that if the older infants in Experiment 1 looked longer at the impossible than at the possible event because they preferred the left location for the object, then the infants in Experiment 2 should look longer at the possible than at the impossible event. On the other hand, if the older infants in Experiment 1 looked longer at the impossible event because they were surprised to see the object found behind the right screen when they had last seen it on the left placemat, then the infants in Experiment 2 should also look longer at the impossible event.

Experiment 2

Method

Subjects

Subjects were 12 full-term infants ranging in age from 7 months, 21 days to 8 months, 16 days (M = 8 months).

Apparatus

The apparatus used in Experiment 2 was identical to that in Experiment 1, with a few exceptions. First, an opening was created in the left wall of the apparatus. This opening was of the same dimensions as the opening in the right wall and was located directly opposite. Second, the ledge in the back of the right screen was moved to the back of the left screen.

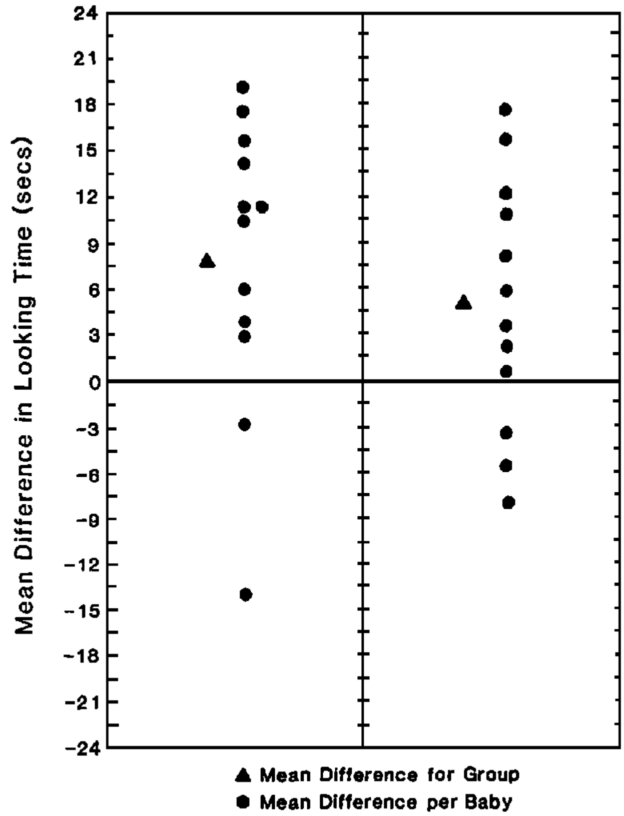

Figure 3. Difference in the mean looking times of the older infants in Experiment 1 (left panel) and the infants in Experiment 2 (right panel) to the impossible and the possible events. (Each dot represents an individual subject. A positive score signifies a longer mean looking time at the impossible than at the possible event; a negative score, in contrast, signifies a longer mean looking time at the possible event.)

Events and Procedure

The events and procedure used in Experiment 2 were identical with those in Experiment 1, with a few exceptions. First, the hand entered the apparatus from the opening in the left rather than in the right wall. Second, the hand reached behind the left instead of behind the right screen to retrieve the object. This meant that the object stood on the left placemat in the possible event and on the right placemat in the impossible event. Finally, the second object was hidden on the ledge behind the left screen during the impossible event.

Results

Figure 3 shows the difference in the infants' mean looking times to the impossible and possible events. (The data obtained for the 8-month-old infants in Experiment 1 are also shown for ease of comparison.) It can be seen that most of the infants in both experiments looked longer at the impossible event.

We analyzed the looking times of the infants in Experiment 2 using a 3 × 2 mixed model ANOVA with Test Pair (first, second, or third pair of test trials) and Event (impossible or possible event) as the within-subjects factors. There was a main effect of Event, $F(1, 55) = 4.76$, $p < .05$, indicating that the infants looked reliably longer at the impossible (M = 38.9, SE = 2.1) than at the possible (M = 34.0, SE = 2.0) event. Although there was a main effect of Test Pair, $F(2, 55) = 16.73$, $p = .0001$, showing that the infants looked reliably less over time, the interaction of Test Pair and Event was not reliable, $F(2, 55) = 0.13$, indicating that the infants' preference for the impossible event did not differ significantly across the three test pairs.

We conducted a second ANOVA comparing the looking times of the infants in Experiments 1 and 2. This analysis was a 2 × 3 × 2 mixed model ANOVA with Experiment (1 and 2) as the between-subjects factor and with Test Pair and Event as the within-subjects factors. As expected, there were reliable main effects of Event, $F(1, 100) = 15.19$, $p = .0002$, (impossible event: $M = 42.1$, $SE = 1.7$; possible event: $M = 35.9$, $SE = 1.5$), and Test Pair, $F(2, 100) = 16.90$, $p = .0001$. There was no main effect of Experiment, $F(1, 22) = 3.64$, $p > .05$, and no reliable interaction involving this factor, all $Fs < 1.79$, $p > .05$.

As in Experiment 1, we carried out a number of analyses to find out whether the infants in Experiment 2 looked reliably longer during the impossible event (a) while the hand was tiptoeing back and forth, (b) while the hand was shaking the object, or (c) both. The infants' mean looking times during the first 15 s of the trials (while the hand was tiptoeing) were 13.2 s ($SE = 0.3$) and 12.8 s ($SE = 0.4$) for the impossible and possible events, respectively, $F(1, 55) = 0.48$. The infants' mean looking times after the first 15 s of the trials (while the hand was shaking the object) were 25.7 s ($SE = 2.0$) and 21.2 s ($SE = 1.9$) for the impossible and possible events, respectively, $F(1, 55) = 4.00$, $p = .05$. These results show that the infants looked reliably longer at the impossible event only *after* the hand reached behind the left screen to retrieve the object.

A final comparison revealed that the infants looked about equally when the object was on the left ($M = 12.8$, $SE = 2.3$) and on the right ($M = 11.0$, $SE = 2.0$) placemats during the familiarization trials, $F(1, 11) = 1.07$, $p > .05$.

Discussion

The infants in Experiment 2, like those in Experiment 1, looked reliably longer at the impossible than at the possible event on all three test pairs, suggesting that they (a) registered the location of the object at the start of each trial, before the screens were pushed in front of the placemats; (b) remembered this information during the 15 s the hand tiptoed back and forth; and (c) were surprised, after seeing the object on the right placemat, to see it retrieved from behind the left screen. These results provide evidence that the infants in Experiment 1 looked longer at the impossible event, not because they preferred the left location for the object, but because they appreciated that the hand could not retrieve an object hidden behind the left screen by reaching behind the right screen.

General Discussion

In the introduction, we reviewed several interpretations of infants' errors in the AB search task. One of these interpretations (Diamond, 1985) attributed infants' perseverative errors to difficulties with action inhibition, and infants' random errors, to memory limitations. The remaining accounts attributed all of infants' search errors to immature or inadequate memory mechanisms (e.g., Bjork & Cummings, 1984; Harris, in press; Schacter & Moscovitch, 1983; Schacter et al., 1986; Sophian & Wellman, 1983; Wellman et al., 1987). However, the results of Experiments 1 and 2 suggest that appeals to the deficiencies of infants' memory to explain their perseverative or their random search errors are unlikely to be accurate. Researchers have reported that 8-month-old infants typically make perseverative errors after delays of 3 s (e.g., Butterworth, 1977; Diamond, 1985; Fox et al., 1979; Gratch & Landers, 1971; Wellman et al., 1987), and random errors, on A as well as B trials, after delays of 6 s (e.g., Diamond, 1985). In marked contrast, the 8-month-olds in the present experiments seemed to have no difficulty remembering where the object was hidden on each trial despite the fact that it remained out of view for 15 s—five times as long as the delay associated with perseverative responding, and two and a half times as long as the delay associated with chance responding. Hence, it is unlikely that infants' inferior search performance could be caused by memory limitations alone.

How, then, should we explain infants' perseverative and random search errors? One possibility, already alluded to earlier, is that these errors reflect difficulties in the *interaction of memory and action*. The results of the pilot experiment reported earlier and those of Experiments 1 and 2 suggest that infants aged 8 months and older possess the memory resources necessary to remember changes in an object's hiding place over the short delays used in the AB task. It is possible that these memory resources, which appear relatively robust when assessed in nonaction tasks, are easily disrupted by the demands of action. With delays of less than 3 s, infants' memory of an object's new hiding place would be used in planning a search response. With longer delays, however, this memory would become superseded by other information (such as where the infants reached on their last successful trial) or lost altogether.

What could be the source of infants' difficulties in integrating their memory and action-generating abilities? The explanation may have to do with the fact that how well infants perform on the AB search task (and on other means–end tasks; cf. Baillargeon, Graber, & Black, 1988; Diamond, 1987) appears to depend on the maturity of their prefrontal cortex. Diamond (1987; Diamond & Goldman-Rakic, 1983, 1985; Diamond, Zola-Morgan, & Squire, in press) found that infant rhesus monkeys aged 1.5 to 2.5 months, and rhesus monkeys aged 5 months or older with bilateral lesions of the dorsolateral prefrontal cortex, produce perseverative errors after delays of 2 to 5 s, as do 7.5- to 9-month-old human infants. In contrast, unoperated adult rhesus and cynomologous monkeys, adult rhesus monkeys with bilateral parietal lesions, and adult cynomologous monkeys with bilateral hippocampal lesions, search correctly even after 10-s delays, as do 12-month-old human infants. These data suggest that correct performance on the AB search task depends on a prefrontal function that matures during the second half of the first year. Although it is still unclear what this prefrontal function consists of, some evidence suggests that it involves the integration of information for purposes of action (e.g., Diamond, 1987; Fuster, 1980). These various lines of evidence suggest the following speculation. Although young infants may have little difficulty remembering information about an object's new hiding place, as evidenced by their successful performances in the present experiments, such information may rapidly be lost when sent to the relatively immature prefrontal structures responsible for the integration of information for, and the planning of, search actions. It should be noted that this explanation leaves open the issue of whether the information passed on to the prefrontal cortex is lost by the time that perseverative errors appear (e.g., Bjork & Cummings, 1984; Harris, in press; Schacter & Moscovitch, 1983; Schacter et al., 1986; Wellman et al., 1987) or only by the time that random errors appear (e.g., Diamond, 1985).

Further research is necessary to decide how best to account for the remarkable gap between infants' ability to reason about (nonsearch tasks) and to act on (search tasks) information about objects' hiding places. Before we leave these speculations behind, we would like to add two comments. One is that finding such a gap is not in itself a discovery. Researchers have reported that infants represent the existence of hidden objects long before they begin to search for them (e.g., Baillargeon, 1987a, 1987b; Baillargeon & Graber, 1987; Baillargeon, Spelke, & Wasserman, 1985; Hood & Willats, 1986; Spelke & Kestenbaum, 1986, cited in Spelke, in press). It will be interesting to find out how the explanation for the lag between permanence and search relates to that for the lag between accurate location memory and accurate search. The second comment is that the foregoing discussion points to the need for bringing into sharper focus the little-understood and little-investigated problem of the relation between cognition and action in infancy (cf. Campos & Berthental, in press).

The foregoing discussion presupposes that the remarkable discrepancy between the results obtained with the present task and with the AB task is due to the fact that the latter task requires action whereas the former task does not. It could be objected that the two tasks differ in several other ways and that any one of these differences might be responsible for the observed discrepancy. Although plausible, this argument seems unlikely, for the following reason. Both the infants in the pilot experiment reported earlier and in Experiments 1 and 2 exhibited accurate location memory over the delays used. Yet these experiments differed in most respects, except for the fact that they relied on an index of surprise that presupposed accurate location memory, rather than on manual search, to test infants. The pilot experiment examined infants' understanding of the fact that a solid object cannot move through the space occupied by another solid object. Experiments 1 and 2, in contrast, tested infants' knowledge of the principle that an object cannot occupy two locations at the same time, or, depending on how one looks at it, cannot move from one location to another without traveling the distance between them. The nature and dimensions of the hidden object and screens in the two experiments were also very different. Finally, whereas the infants in the pilot experiment saw several hidings in one location before the object was moved to the other location (recall that the event was repeated without pause until the trial ended), the infants in the present experiment saw a single hiding before the object's location was reversed.

Unlike the 8-month-old infants in Experiment 1, the 7.5-month-olds (M = 7 months, 10 days) tended to look equally at the impossible and the possible events. At least three interpretations could be offered for this result. One is that the younger infants forgot the object's location during the 15 s the hand tiptoed back and forth. This explanation, if correct, would be surprising in that it would point to a very sharp increase in infants' information-retention capacity between 7 and 8 months of age (Moscovitch, 1985, proposed a similar development). A second interpretation is that the younger infants remembered the object's location during the 15-s delay but were not surprised at the impossible event because they did not understand that the object could not be retrieved from behind the right screen if it stood on the left placemat. The infants might not have known that an object cannot appear at two separate points in space without having travelled from one point to the other or, more fundamentally, that an object can only be in one place at a time (Harris, 1983, argued that this last conceptual difficulty contributes to infants' search errors). Yet another interpretation is that the younger infants had both the memory capacity and the conceptual knowledge tapped by the task but could not demonstrate these abilities because the attentional demands of the task were too great. This explanation suggests that the infants might perform better with a different task or a different version of the same task. Further experiments are needed to decide among these three possibilities.

The results of the experiments reported here indicate that, when given a task that does not require manual search, 8-month-old infants remember trial-to-trial changes in an object's location over delays considerably longer than those that result in perseverative or random errors in the AB search task. The discovery of such a marked discrepancy between infants' ability (a) to remember accurately the location of hidden objects and (b) to search accurately for hidden objects raises important questions about the organization of action and the interaction of action and cognition in infancy.

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