JOURNAL OF COGNITION AND DEVELOPMENT, *3*(2), 119–142

Infants' Object Search: Effects of Variable Object Visibility Under Constant Means-End Demands

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Why do infants have difficulty searching for objects hidden by occluders before 8 months when other evidence has indicated they are sensitive to hidden objects months earlier? One explanation suggests that infants know hidden objects exist but lack the means-end skill to retrieve them from occluders. However, this experiment explores the unique contribution of object visibility by presenting 6- and 10-month-old infants with visible and hidden objects that could be retrieved with little to no means-end skill. Results indicate that 6-month-old infants searched significantly less for hidden objects than visible objects, although both conditions were equated for means-end demands. In contrast, there were no differences among 10-month-old infants. These results highlight the effect of object visibility on search and indicate that a means-end deficit cannot be the only cause of search problems. Explanations for the effect of object visibility are discussed.

Why do infants fail to search for objects hidden by occluders before 8 months when they seem sensitive to hidden objects months earlier in other tasks? Infants appear sensitive to hidden objects in violation-of-expectation studies by 3½ months, and in reaching-in-the-dark studies by 5 to 6 months. What, then, prevents them from searching for hidden objects in the classic manual search task until months later? These inquiries raise fundamental questions about the nature and development of early cognition. A prevailing explanation is that infants have a deficit in the means-end skill needed to retrieve objects from occluders despite knowing that hidden objects continue to exist (Baillargeon, Graber, DeVos, & Black, 1990; Bower & Wishart, 1972; Clifton, Perris, & Bullinger, 1991; Diamond, 1991; Rader, Spiro, &

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Firestone, 1979). Evidence supporting this means-end deficit account is described next, as is other evidence challenging the account. The purpose of this experiment was to test the effects of manipulating object visibility while diminishing and equating means-end demands across conditions. The aim is to further probe the puzzle of why infants fail to consistently search for hidden objects for several months after they appear to be sensitive to hidden objects in other paradigms.

LIMITATIONS OF MANUAL SEARCH

Infants' problems with searching for objects hidden by occluders were traditionally attributed to their lack of the object concept (Piaget, 1952, 1954). According to this account, during the first 2 years of life, infants gradually construct the concept that objects are permanent, independent entities. It is not until about 8 to 10 months that infants search for completely hidden objects and generalize their search to situations involving different objects and occluders (Piaget, 1952, 1954). Infants' limitations in searching for hidden objects before approximately 8 to 10 months have been replicated independently. At 5 and 6 months, infants have great difficulty retrieving an object that they previously watched being hidden (e.g., Bower & Wishart, 1972; Gratch, 1972; Gratch & Landers, 1971; Willatts, 1984). However, active search and retrieval increase between 6 and 12 months (e.g., Bruner, 1970; Kimball, 1970; Willatts, 1984). Such results were originally interpreted as evidence that younger infants lack the concept of object permanence.

However, this conclusion has been challenged in recent decades by infants' behavior in other paradigms. Several researchers have argued that infants' knowledge about hidden objects is underestimated in the classic manual search task (in which an object is hidden by an occluder) because the task requires a level of problem-solving skill that younger infants may lack (Baillargeon et al., 1990; Bower & Wishart, 1972; Clifton, Perris, & Bullinger, 1991; Diamond, 1991; Rader et al., 1979). The specific deficit is one of means-end skill: an inability to conjoin actions to pick up the occluder to get to the object underneath (Bower & Wishart, 1972). Retrieving the desired object is the goal or end, and displacing the occluder is the means to that end. According to this account, infants younger than 8 months are not capable of this level of skill, despite knowing that the hidden object continues to exist. In support of this explanation, infants' behavior in tasks without means-end demands suggests that they are sensitive to the existence of hidden objects.

Support for the Means-End Deficit Account

Because of criticism of manual search tasks, researchers turned to investigating infants' visual attention to occlusion events. Because such events require no means-end skill, they may be less likely to underestimate infants' knowledge. In the violation-of-expectation paradigm (e.g., Baillargeon, Spelke, & Wasserman, 1985), infants watch events in which a hidden object undergoes possible and impossible transformations. For example, infants may see a moving occluder bump into the hidden object behind it and stop moving, or they may see the occluder move through the space occupied by the hidden object as if the object no longer existed (Baillargeon et al., 1985). If infants' expectations are violated by impossible events, then they should look longer at impossible events than possible events. In many studies using this paradigm, infants from 3½ to 8 months do look significantly longer at impossible than possible events (Baillargeon, 1987; Baillargeon & Graber, 1987; Baillargeon et al., 1990; Baillargeon et al., 1985; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wynn, 1992). This demonstration of early sensitivity to hidden objects in situations without means-end demands is consistent with the means-end deficit account.

Infants' behavior with objects hidden in the dark also supports the means-end deficit account and indicates early sensitivity to hidden objects. In this paradigm, the object is concealed by darkness rather than by a physical barrier, which allows infants to retrieve the object with a direct reach instead of a means-end action sequence. For example, 5-month-old infants who saw an object in front of them in the light retrieved it after the lights were turned off (Bower & Wishart, 1972). At 5 months, infants also reached more often in the dark to a location where they just saw an object in the light than to a control location where they saw no object (Hood & Willatts, 1986). Infants who were 6 to 8 months old also reached in the dark for objects that emitted either continuous sound cues (Clifton, Perris, & Bullinger, 1991; Clifton, Rochat, Litovsky, & Perris, 1991) or sound cues that ceased before search began (Goubet & Clifton, 1998; McCall & Clifton, 1999). These results support the means-end deficit account because infants can retrieve the object with a simpler direct reach. However, other evidence described next suggests that a means-end deficit may not be the only explanation for infants' search difficulties.

Challenges to the Means-End Deficit Account

One approach attempting to indirectly explore the means-end deficit account involves equating means-end demands for retrieving hidden and visible objects by introducing them into both opaque and transparent conditions. If infants have less difficulty with transparent barriers than with opaque barriers, then a means-end deficit cannot be the only cause of search problems. Yet when means-end demands are equated in both visible and hidden conditions, 5- to 8-month-old infants retrieve visible objects more (Bower & Wishart, 1972; Gratch, 1972; Munakata, McClelland, Johnson, & Siegler, 1997; Neilson, 1982; Shinskey & Munakata, 2001). For example, 7-month-old infants who learned to pull a towel to retrieve an object resting on top of it showed more toy-guided retrieval (discriminated between toy and no-toy trials) with a transparent barrier than with an opaque barrier (Munakata et al., 1997). Likewise, 5- to 8-month-old infants more often retrieved a toy from a transparent curtain than from an opaque curtain (Shinskey, Bogartz, & Poirier, 2000).

The goal of the experiment presented here was to further test the effects of object visibility on infants' search when means-end demands were held constant in a manner different from that used previously. The approach taken here is similar to that described previously, in that means-end demands were equated for retrieving hidden and visible objects. However, it is different in an important way. Instead of adding means-end demands to both opaque and transparent conditions, means-end demands were removed from or reduced in both opaque and transparent conditions. For example, objects were placed in water (transparent condition) or milk (opaque condition), or were placed behind transparent or opaque curtains with a slit cut down the middle. Such an approach has a specific advantage over tasks that add means-end demands. Adding means-end demands typically requires training infants in a particular means-end skill that they do not spontaneously use (e.g., Munakata et al., 1997; Shinskey & Munakata, 2001). Yet, such training may have other effects on infants' behavior. For example, mastering the means-end skill might leave fewer cognitive resources available for representing the hidden object. The present approach is also similar to that of the reaching-in-the-dark paradigm because means-end demands were removed or diminished to allow more direct reaching. Yet it is different because infants received the events in the light. Thus, although the approach used here bears some similarities to the two previous approaches, converging evidence from different tasks and laboratories will contribute to a comprehensive account of the development of infants' behavior with hidden objects.

PHASE 1

In the first phase of the experiment, 6- and 10-month-old infants received three events in which means-end demands were held constant while object visibility varied. No event required means-end skill, and object visibility varied from fully visible to partly visible to fully hidden. Objects were placed in a well containing water (fully visible) or milk (either partly visible or fully hidden). Means-end skill was not required to search for the object in any event because infants could retrieve the object with a straight reach into the well. If object visibility contributes to infant's search difficulties, then 6-month-old infants should search less when the object is hidden than when it is visible or partly visible. In contrast to the prediction that 6-month-old infants would search less in the hidden events than in the visible and partly-visible events, 10-month-old infants were expected to search equally often on the three events.

Method

Participants

Thirty-six 6-month-old infants (M = 6 months, 2 weeks; 17 girls and 19 boys) and eighteen 10-month-old infants (M = 10 months, 2 weeks; 10 girls and 8 boys) participated. Twenty additional infants were tested but not included in the sample due to premature birth (1), visual impairment (1), failure to contact the object during familiarization (1), failure to contact the milk during familiarization (1), outlying data points (1), experimenter error (2), fussiness (3), and disinterest (10; e.g., little or no interest in the object when visible). Participants were recruited from state birth records for two neighboring counties. Parents were contacted first by letter and then by telephone, and participation was voluntary.

Apparatus, Materials, and Stimuli

An infant seat was fastened to a wooden table (75 × 115 cm) that had a 22 × 22-cm hole cut in it, which was centered in front of the infant seat and 2.5 cm from the infant. A 22- × 22- × 9-cm (2.5-liter) Tupperware bowl placed in the hole served as a well. The well contained a round, 1.4-liter plastic Tupperware bowl (17 × 17 × 7 cm), in which the liquids and objects were placed. Materials included a piece of Plexiglas (25 × 25 cm) held between the infant and the bowl to prevent the infant from searching before the object was placed completely in the bowl. The bowl contained 1.4 liters of either lukewarm water or lukewarm milk. The milk consisted of ½ cup nonfat dry milk mixed with water. The stimuli consisted of a yellow and white plastic ball (16 cm circumference) with a bell inside of it, an identical purple-and-white ball, and an ornamental brass hook (6 × 3½ cm diameter).

Recording Equipment

Two video cameras recorded the session. One captured the infant's face, whereas the other, placed directly above the infant, provided an aerial view of the infant and the table. A video mixer recorded the two camera inputs on one videotape. The picture was displayed on two monitors in an adjoining room. The parent viewed one of the monitors through a window between the rooms. The aerial view was the primary image on the monitor, with an inset in one corner of the screen showing the infant's face. To time the events, the experimenter used a metronome that clicked once every second.

Events and Design

An initial familiarization event with one of the three objects preceded a familiarization event with either the water or the milk. There were three test events (see Figure 1).[1] In the water event, the object was completely submerged in the bowl of water. In the milk-visible event, 1cm of the object placed in a bowl of milk pro-

[1]An additional means-end event was presented in which an object was hidden under a cloth. However, the event is not included in the analysis because object visibility was not varied systematically, as it was in the direct-reach events. Therefore, the appropriate comparisons could not be made.

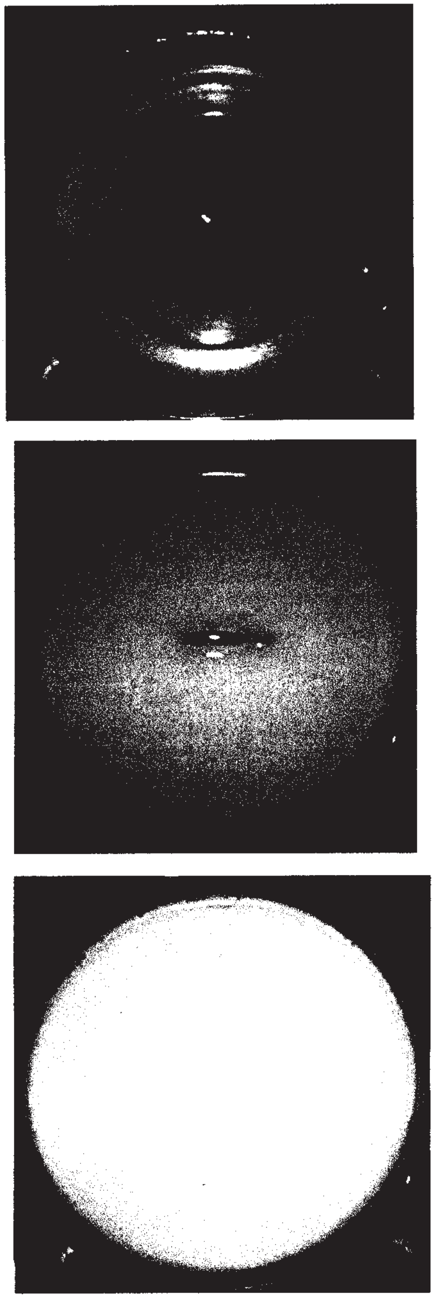

FIGURE 1 The three events of Phase 1: water, milk-visible, and milk-hidden.

truded above the surface. In the milk-hidden event, the object was completely submerged in milk. To simplify the design and procedure, objects and events were not crossed. The purple-and-white ball was used in the water event, the brass hook was used in the milk-visible event, and the yellow-and-white ball was used in the milk-hidden event. However, infants appeared equally motivated to reach for the three objects. Before the test events, all infants retrieved each of the three objects from the empty well.

The design was a 2 (age groups) × 3 (events) × 4 (trials) factorial design with age and event as between-subjects factors and trial as a within-subjects factor. Each of the three event groups included twelve 6-month-old and six 10-month-old infants. Each infant received one test event four times for a total of four test trials.

Procedure

The parent signed a consent form before the session began. During the session, the infant sat in the infant seat at the table. The parent sat to the infant's right, but facing the opposite direction. The experimenter sat across the table from the infant. The parent observed the infant on a television monitor through the window to the adjoining room. Infants who could not sit upright in the infant seat were placed on the parent's lap. The parent was asked not to interact with the infant unless the infant became fussy.

Each infant first received one familiarization trial with each of the three objects. The experimenter shook the ball or tapped the hook on the table until the infant fixated it, and held the Plexiglas between the infant and the bowl while placing the object in the bowl. If the infant did not retrieve the object after the Plexiglas was removed, the event was repeated with the same object or with additional objects until a trial ended with retrieval.

Next, infants in the water group were familiarized with the water and infants in the two milk groups were familiarized with the milk. The experimenter placed the container of liquid in the well in front of the infant. If the infant did not spontaneously reach into the liquid, the experimenter put her hand into the liquid as a demonstration and encouraged the infant to do the same. Familiarization ended when the infant twice submerged at least one hand into the liquid, up to or past the knuckles.

On test trials, the experimenter first shook the ball or tapped the hook on the table until the infant fixated it. While holding the Plexiglas between the infant and the well, the experimenter tapped the object across the table five times on approach to the well, and then placed the object in the liquid while the infant was looking. The experimenter then removed the Plexiglas and began timing the 15-sec search period. Trials ended with retrieval, or after 15 sec elapsed. The infant was allowed to hold the object for several seconds between trials.

Measures, Missing Data, and Interobserver Reliability

Three measures assessed manual search on each trial:

1. *Object retrieval:* whether or not the infant grasped the object and lifted it out of the bowl (1 or 0).
2. *Object contact*: whether or not the infant contacted the object with any part of the hand or arm while looking within the boundaries of the well (1 or 0).
3. *Liquid contact*: whether or not the infant contacted the liquid with any part of the hand or arm while looking within the boundaries of the well (1 or 0).

Because looking behavior in other studies seemed to reflect sensitivity to hidden objects, infants' visual attention to the events was also measured. Assessing visual attention may be informative about any effects that object visibility may have on search. Three measures assessed visual attention on each trial:

1. *Percentage of trial looking away*: percentage of each trial the infant spent looking outside the boundaries of the well (number of seconds looking away divided by number of seconds trial lasted).
2. *Duration of first look*: number of seconds the first look toward the well lasted.
3. *Duration of first look away*: number of seconds the first look away from the well lasted.

Among 6-month-old infants, there were no missing data. Among 10-month-old infants, one missing score due to experimenter error was estimated using a weighted average of scores for the remaining three trials for the infant and scores for the same trial for the other 10-month-old infants in the same event group. A second observer (not blind to condition) coded just over one third of the participants (fourteen 6-month-old infants and seven 10-month-old infants). Agreement occurred on 100% of cases (84 judgments) for object retrieval, object contact, and liquid contact. Pearson r was .98 for percentage of trial looking away, .89 for duration of first look in seconds, and .90 for duration of first look away in seconds.

Results

Manual Search

The prediction was that 6-month-old but not 10-month-old infants would search less when the object was hidden than when it was visible. Because the hypothesis made specific predictions about the comparison between the two visible events and the hidden event, planned contrasts were conducted rather than global F tests. For each measure, the water and milk-visible groups were averaged together and tested against the milk-hidden group. Developmental changes were also explored by testing for an interaction effect of Age × Event on the contrast. The means are displayed in Figure 2.

Object retrieval. As predicted, 6-month-old infants in the water and milk-visible groups retrieved the object more often than infants in the milk-hidden group, $t(33) = 6.41, p < .001$. They retrieved the object on 83% ($SE = 6.41$) of water trials and 85% ($SE = 4.82$) of milk-visible trials, but only 27% ($SE = 9.46$) of milk-hidden trials. In contrast, there were no differences among the 10-month-old groups, $t(15) = .84, p > .10$. Six- and 10-month-old infants also differed from each other, as revealed by an interaction of Age × Event, $t(48) = 4.64, p < .001$. These results suggest that object visibility contributes to infants' search difficulties. Analyses of the remaining measures of manual search yielded the same pattern.

Object contact. As predicted, 6-month-old infants in the water and milk-visible groups contacted the object more often than infants in the milk-hidden group, $t(33) = 4.78, p < .001$. They contacted the object on 100% ($SE = 0.00$) of water trials and 96% ($SE = 4.17$) of milk-visible trials, but only 54% ($SE = 12.24$) of milk-hidden

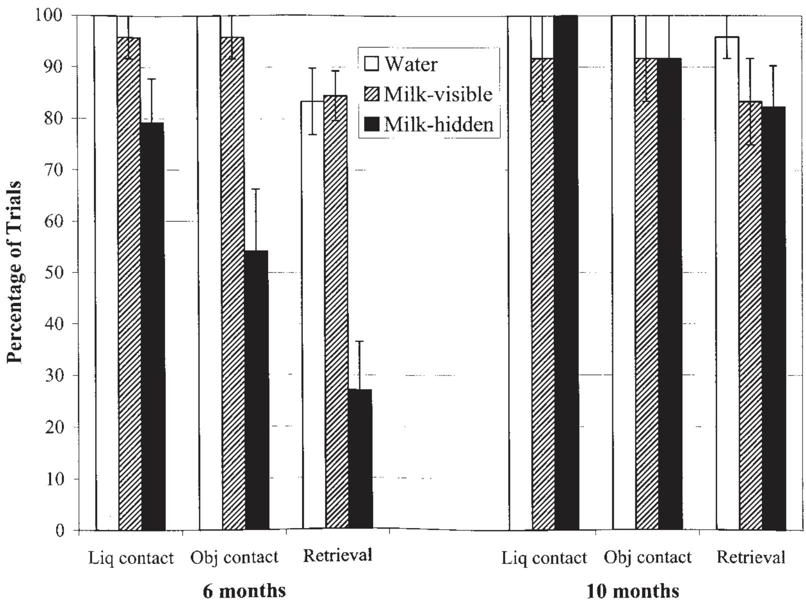

FIGURE 2 Percentage of trials in which infants engaged in manual search in Phase 1 as a function of age and event.

trials. In contrast, there were no differences at 10 months, $t(15) = .50, p > .10$. Six- and 10-month-old infants also differed from each other, $t(48) = 3.35, p < .01$.

Liquid contact. As predicted, 6-month-old infants in the water and milk-visible groups contacted the liquid more often than infants in the milk-hidden group, $t(33) = 2.77, p < .01$. They contacted the liquid on 100% ($SE = 0.00$) of water trials and 96% ($SE = 4.17$) of milk-visible trials, but only 79% ($SE = 8.61$) of milk-hidden trials. In contrast, there were no differences at 10 months, $t(15) = -.71$. However, 6- and 10-month-old infants did not differ from each other, as indicated by the absence of an interaction between Age × Event, $t(48) = 1.39, p > .10$.

Visual Attention

Visual attention may also reveal information about infants' knowledge of hidden objects. The prediction was that 6-month-old infants would spend more time looking away from the object's location when it was hidden than when it was visible. However, 10-month-old infants were expected to fixate the object's location whether the object was visible or not. As with the previous measures, planned contrasts were conducted rather than global F tests. For each measure, the water and milk-visible groups were combined and tested against the milk-hidden group, and developmental changes were explored by testing for an interaction effect of Age × Event. The means are displayed in Table 1.

Percentage of trial looking away. As predicted, 6-month-old infants spent more of the trial looking away from the object's location when the object was hid-

TABLE 1
Means and Standard Errors for Measures of Visual Attention in Phase 1 as a Function of Age and Event

	Event					
	Water		*Milk-Visible*		*Milk-Hidden*	
Measure	*M*	*SE*	*M*	*SE*	*M*	*SE*
Trial looking away (%)						
6 months	4.85	1.51	7.10	2.24	40.40	7.68
10 months	6.74	1.82	16.01	6.40	19.94	3.28
Duration of first look (sec)						
6 months	6.38	0.82	6.02	0.72	3.14	0.58
10 months	3.70	0.38	2.88	0.41	3.16	0.80
Duration of first look away (sec)						
6 months	0.49	0.15	0.68	0.20	3.38	0.85
10 months	0.38	0.16	0.60	0.21	1.22	0.45

den than when it was visible, $t(33) = -5.98$, $p < .001$. They spent only 5% (SE = 1.51) of the trial looking away from the well in the water group and only 7% (SE = 2.24) in the milk-visible group, but 40% (SE = 7.68) in the milk-hidden group. There were no differences at 10 months, $t(15) = -1.63$, $p > .10$. Six- and 10-month-old infants also differed from each other, as revealed by an interaction of Age × Event, $t(48) = -4.77$, $p < .001$.

Duration of first look. Six-month-old infants' first look was shorter when the object was hidden than when it was visible, $t(33) = 3.51$, $p < .01$. Their first look lasted an average of 6.38 sec (SE = .82) in the water group and 6.02 sec (SE = .72) in the milk-visible group, but only 3.14 sec (SE = .58) in the milk-hidden group. There were no differences at 10 months, $t(15) = .56$, $p > .10$. Six- and 10-month-old infants also differed from each other, $t(48) = 2.38$, $p < .05$.

Duration of first look away. Finally, 6-month-old infants' first look away was longer when the object was hidden than when it was visible, $t(33) = -4.44$, $p < .001$. Their first look away lasted 0.49 sec (SE = .15) in the water group and .68 sec (SE = .20) in the milk-visible group, but 3.38 sec (SE = .85) in the milk-hidden group. There were no differences at 10 months, $t(15) = -1.96$, $p > .10$. Six- and 10-month-old infants also differed from each other, as revealed by an interaction of Age × Event, $t(48) = -3.75$, $p < .001$.

Discussion

The results indicate that factors other than means-end demands can contribute significantly to infants' search difficulties. Each of the three events had the same means-end demands (i.e., none), and yet when the object was hidden rather than visible, 6-month-old infants searched less. They were less likely to contact the liquid, contact the object, and retrieve the object. Furthermore, when the object was hidden rather than visible, 6-month-old infants spent more of the trial looking away, had a shorter first look, and had a longer first look away. In contrast, there were no differences at 10 months. The manual search results suggest that a means-end deficit is not the only cause of search difficulties. However, visibility of the object appears to play an important role at 6 months, as indicated by both manual search and visual attention.

An additional phase of testing was undertaken to further address the effects of manipulating object visibility while holding means-end demands constant, with a different search task. Behavior similar to that in Phase 1 but with a different type of occluder would help to establish the robustness of the finding and support the interpretation that a means-end deficit is not the only cause of search problems. Thus, means-end demands for retrieving visible and hidden objects were also equated in Phase 2 by reducing them in both transparent and opaque events, but a different task was used. As in the first phase, 6-month-old and 10-month-old infants were presented with events in which objects were completely visible, partly visible, or completely hidden.

PHASE 2

Six- and 10-month-old infants were presented with three events that allowed object retrieval with little or no means-end skill: Infants could retrieve the object by reaching directly through a curtain with a slit cut down the middle. The object was completely visible behind a transparent curtain, partly visible behind an opaque curtain with a hole cut in the center, or completely hidden behind an opaque curtain with no hole cut in it (see Figure 3). The prediction was that 6-month-old infants would search less when the object was hidden than when it was visible or partly visible, even though the events were equated for means-end demands. In contrast, no differences were expected at 10 months. In addition, it was expected that 6-month-olds but not 10-month-old infants would engage in less visual attention when the object was hidden than when it was visible.

Method

Participants

Phase 2 tested the same thirty-six 6-month-old infants as Phase 1 plus an additional twelve 6-month-old infants, for a total of 48 (M = 6 months, 2 weeks; 23 girls and 25 boys). In addition to the same eighteen 10-month-old infants tested in Phase 1, Phase 2 also tested another 6 infants at 10 months for a total of 24 (M = 10 months, 2 weeks; 14 girls and 10 boys). The other exceptions were that 2 infants participated in the first phase and not the second due to fussiness (1) and disinterest (1), and 2 participated in the second phase but not the first due to experimenter error (1) and failure to contact the milk during familiarization (1).

Apparatus, Materials, Stimuli, and Recording Equipment

The same table and infant seat were used as in Phase 1. The apparatus was a wooden board (25.5 × 28 cm) with two wooden dowels (21 × 2 cm) fastened vertically with screws to the two front corners. A metal U-shaped hook on the back of each dowel, 16 cm from the base of the platform, held the curtain dowel (35 × 1.25 cm) in a horizontal position. Each end of the curtain dowel was capped with a cross-section of a larger dowel (2.25 × 1.5 cm).

Each of the three curtains (18 × 17 cm), attached to separate dowels, had a slit cut directly down the middle from the top to bottom. The transparent curtain consisted of tulle fabric. The hole curtain consisted of opaque white polyester fabric

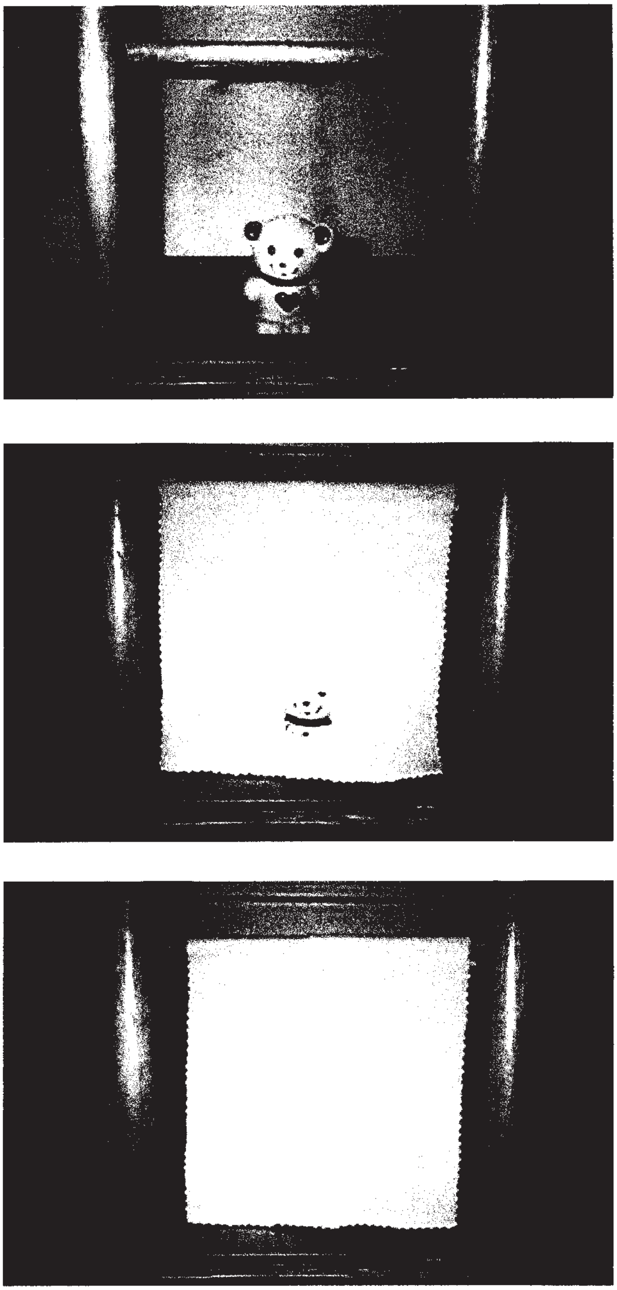

FIGURE 3 The three events of Phase 2: transparent curtain, hole curtain, and opaque curtain.

with a 2-cm square hole cut in its center, 2.5 cm from the bottom edge. The opaque curtain was identical to the hole curtain except it had no hole.

The stimuli consisted of four rubber toys: a yellow bear (7 × 5.5 × 4 cm), a green frog (4.5 × 4.5 × 6 cm), a pink pig (7.5 × 6.5 × 5.5 cm), and a yellow duck (5 × 4.5 × 5.5 cm). The Plexiglas from Phase 1 was used at the beginning of Phase 2 to support the display of the four toys over the well in the table. Except for the duck, each toy made a squeaking noise when squeezed. Recording equipment was identical to that in the first phase.

Events and Design

The first event familiarized the infant with the objects. The infant was given his or her preference of the four rubber toys, followed by one trial of reaching for the preferred toy on the apparatus. The infant was then familiarized with the transparent, hole, and opaque curtains before receiving the three test events.[2]

In the transparent curtain test event, the experimenter placed the object on the apparatus, hung the transparent curtain in front of the object, and pushed the apparatus to the infant. The hole and opaque curtain events were identical except for curtain type. Each infant received three trials for each of the three test events, for a total of nine trials.

The design was a 2 (age groups) × 3 (events) × 3 (trials) × 6 (orders) factorial design, with age and order as between-subjects factors, and event and trial as within-subjects factors. There were forty-eight 6-month-old infants in the younger group and twenty-four 10-month-old infants in the older group. The three events were given in three blocks for a total of nine trials. The transparent event always occurred in the last (third) place within each block to minimize the number of event orders. The other two events were presented in counterbalanced order within each block. Each of the six orders was presented to eight 6-month-olds and four 10-month-olds.

Procedure

The seating arrangements were identical to that of Phase 1. The experimenter began the session by placing the four toys on the Plexiglas and pushing the Plexiglas toward the infant to allow him or her to choose a preferred toy. The experimenter judged the infant's preference based on the infant's looking or reaching. The preferred toy was used for the first block of trials, and two other toys were used for the remaining two blocks.

[2]An additional means-end event was presented in which a lit flashlight was covered with a cloth so that the light shone through the fabric. However, the event is not included in the analysis because object visibility was not varied systematically, as it was in the three curtain events. Therefore, the appropriate comparisons could not be made.

Next, the infant was familiarized with reaching for an object on the apparatus. The trial began with the apparatus in front of the infant but out of reach. The experimenter either squeaked the object or tapped it on the apparatus until the infant fixated it, and then bounced the object along the platform of the apparatus (back to front from the infant's perspective) until it came to rest approximately 5 cm from the front edge of the apparatus. Then the experimenter pushed the apparatus to the infant for retrieval.

Next, infants were familiarized with each of the three curtains. Each trial began with the apparatus out of reach. The experimenter placed the curtain on the apparatus and pushed the apparatus to the infant for manipulation. Infants received the transparent curtain first, followed by the hole curtain and then the opaque curtain. If the infant did not put his or her hand through the slit in the curtain, the experimenter demonstrated that her own hand could go through the slit.

Test trials began with the apparatus out of reach. The experimenter either squeaked or tapped the toy until the infant fixated it, bounced the toy to the front of the apparatus, and hung the appropriate curtain in front of it. The experimenter then pushed the apparatus to the infant, and began timing the 15-sec trial. If the experimenter judged the infant to be uninterested in the toy on the first two visible curtain events (transparent and hole curtains), the toy was replaced on the next trial. Otherwise each block of trials used a different toy. Infants could hold the object for several seconds between trials.

Measures, Missing Data, and Interobserver Reliability

As in Phase 1, three measures assessed manual search on each trial.

1. *Object retrieval*: whether or not the infant grasped the object and drew it toward the body and past the two front poles of the apparatus (1 or 0).
2. *Object contact*: whether or not the infant contacted the object with any part of the hand or arm, whether through the curtain or not, while looking within the boundaries of the curtain (1 or 0).
3. *Curtain contact*: whether or not the infant contacted the curtain with any part of the hand or arm while looking within its boundaries (1 or 0).

As in Phase 1, to explore the role of object visibility on infants' search, three measures assessed visual attention on each trial.

1. *Percentage of trial looking away*: percentage of each trial the infant spent looking outside the boundaries of the curtain (number of seconds looking away divided by number of seconds trial lasted).
2. *Duration of first look*: number of seconds the first look toward the curtain lasted.

3. *Duration of first look away*: number of seconds the first look away from the curtain lasted.

For 6-month-old infants, there were 10 missing scores (due to experimenter error or because infants quit the session early because of fussiness). Missing scores were estimated using a weighted average of the infant's scores for the remaining trials of the same event and the scores from the same event and trial for the other 6-month-old infants with the same event order. For 10-month-old infants, there were 12 missing scores (due to experimenter error). The same method of estimating missing scores was used for 10-month-old infants as for 6-month-old infants, except that because of the smaller number of infants, order of events was disregarded.

A second observer (not blind to condition) coded one third of the participants (sixteen 6-month-olds and eight 10-month-olds). Agreement was 96% (214 of 223 judgments) for object retrieval, 94% (210 out of 223) for object contact, and 96% (215 out of 223) for curtain contact. Pearson r was .91 for percentage of trial looking away. However, because r was only .76 for duration of first look in seconds and .65 for duration of first look away in seconds (based on the coding of a different observer than that in Phase 1), these two measures were not included in the analyses.

Results

Manual Search

The prediction was that 6-month-old infants but not 10-month-old infants would search less when the object was hidden than when it was visible. As for the first phase, planned contrasts were conducted because the hypothesis made specific predictions about the comparison between the two visible events and the hidden event. For each measure, each infant's average opaque curtain score was subtracted from the average of his or her transparent and hole curtain scores, and the null hypothesis that the difference would be zero was tested. The means are displayed in Figure 4.

Object retrieval. As predicted, 6-month-old infants more often retrieved the object on the visible events (transparent curtain and hole curtain) than on the hidden event (opaque curtain), $t(47) = 10.30$, $p < .001$. They retrieved the object on 75% ($SE = 4.27$) of transparent curtain trials and 52% ($SE = 5.34$) of hole curtain trials, but only 18% ($SE = 3.74$) of opaque curtain trials. There were no differences at 10 months, $t(23) = 1.58$, $p > .10$. Six- and 10-month-old infants also differed from each other, $F(1, 71) = 25.00$, $p < .001$.

Object contact. As predicted, 6-month-old infants more often contacted the object on the visible events than on the hidden event, $t(47) = 7.66$, $p < .001$. They contacted the object on 99% ($SE = .97$) of transparent curtain trials and 87% ($SE =$

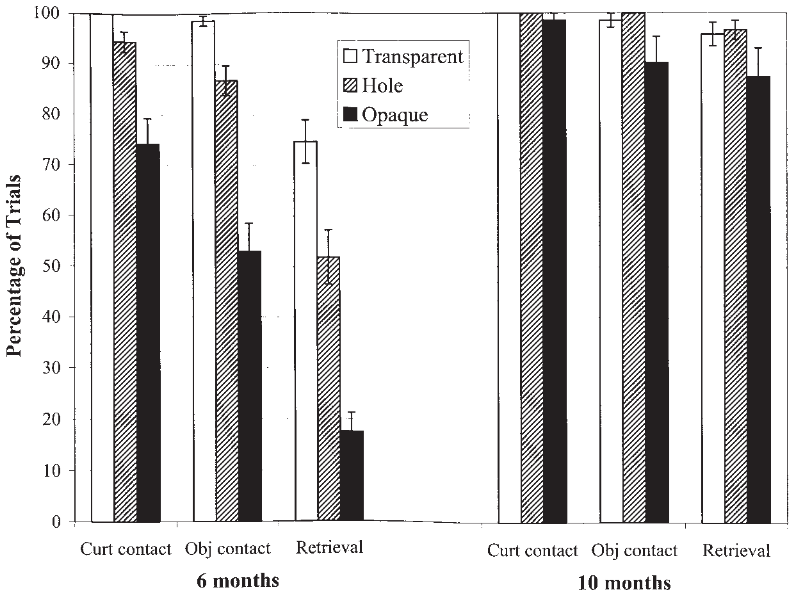

FIGURE 4 Percentage of trials in which infants engaged in manual search in Phase 2 as a function of age and event.

2.93) of hole curtain trials, but only 53% ($SE = 5.61$) of opaque curtain trials. There were no differences at 10 months, $t(23) = 1.73$, $p > .10$. Six- and 10-month-old infants also differed from each other, $F(1, 71) = 13.94$, $p < .001$.

Curtain contact. As predicted, 6-month-old infants more often contacted the transparent and hole curtains than the opaque curtain, $t(47) = 4.73$, $p < .001$. They contacted the transparent curtain on 100% ($SE = 0.00$) of the trials and the hole curtain on 94% ($SE = 2.07$) of the trials, but the opaque curtain on only 74% ($SE = 5.07$) of the trials. There were no differences at 10 months, $t(23) = 1.00$, $p > .10$. Six- and 10-month-old infants also differed from each other, $F(1, 71) = 9.62$, $p < .01$.

Visual Attention

The contrast of the opaque curtain event with the transparent and hole curtain events was also conducted with the visual attention measure of the percentage of the trial spent looking away from the object's location.

Percentage of trial looking away. As predicted, 6-month-old infants spent more of the trial looking away from the object's location on the hidden event (opaque curtain) than on the visible events (transparent and hole curtains), $t(47) = -9.42$, $p < .001$. They looked away for only 10% ($SE = 2.03$) of the time on transparent curtain trials and 18% ($SE = 2.45$) of the time on hole curtain trials, but 40% ($SE = 3.07$) of the time on opaque curtain trials. In contrast, 10-month-old infants fixated the object's location on the hidden event to the same degree as on the visible events, $t(23) = -1.01$, $p > .10$. They looked away for 6% ($SE = 1.99$) of the time on transparent curtain trials, 5% ($SE = 1.55$) of the time on hole curtain trials, and 8% ($SE = 2.48$) of the time on opaque curtain trials. Six-and 10-month-old infants also differed from each other, $F(1, 71) = 32.90$, $p < .001$.

Discussion

As in Phase 1, 6-month-old infants in Phase 2 were less likely to search for the object on the event in which it was completely hidden than the two events in which it was visible or partly visible. When the object was hidden rather than visible or partly visible, 6-month-old infants less often contacted the curtain, contacted the object, and retrieved the object. In contrast, there were no differences among 10-month-old infants. These results suggest that a deficit in means-end skill is not the only cause of young infants' search problems. In addition, 6-month-old infants but not 10-month-old infants spent more of the trial looking away on the hidden event than on the visible and partly visible events. In combination, the results of manual search and visual attention suggest that object visibility plays an important role in infants' search difficulty at 6 months.

One caveat, however, is that the curtain events were not unambiguously lacking in means-end demands. Although they were designed to allow infants to retrieve the object with a direct reach through the slit in the curtain, not all infants who searched for the object did so with a direct reach. In addition to reaching through the slit, infants also retrieved the object by reaching under the curtain, grasping the object through the curtain, pulling the curtain up, pulling the curtain to one side, or pulling both halves of the curtain in opposite directions. Thus, on some trials, infants used a greater degree of means-end skill to retrieve the object than on other trials. Unfortunately, these behaviors were not discriminated in scoring; thus, the curtain events may not be accurately described as lacking means-end demands in the same way that the liquid events of Phase 1 are. Regardless, the three curtain events were equated for means-end demands, such that behavioral differences among the three events cannot be attributed to deficits in means-end skill.

GENERAL DISCUSSION

When means-end demands were equated in hidden and visible events—being either removed or diminished—6-month-old infants but not 10-month-old infants engaged in less manual search with hidden objects than with visible and partly visible objects. In Phase 1, 6-month-old infants but not 10-month-old infants were significantly less likely to contact the liquid, contact the object, or retrieve the object in the hidden event (i.e., milk-hidden) than in the visible (i.e., water) and partly visible (i.e., milk-visible) events. These findings suggest that object visibility plays an important role in infants' search. The effect of object visibility is also highlighted by the finding that in the hidden event, 6-month-old infants but not 10-month-old infants spent more of the trial looking away from the object's location, had a shorter first look, and had a longer first look away (relative to the visible and partly visible events).

Infants showed the same pattern in Phase 2, in which objects were visible, partly visible, or hidden behind curtains with a slit cut down the middle: 6-month-old infants but not 10-month-old infants were more likely to contact the occluder, contact the object, and retrieve the object in the visible (i.e., transparent curtain) and partly visible (i.e., hole curtain) events than in the hidden event (i.e., opaque curtain). The results highlight the role that object visibility plays in 6-month-old infants' search difficulty, which is also emphasized by the finding that 6-month-old infants but not 10-month-old infants spent more of the trial looking away in the hidden event, relative to the visible and partly visible events.

Thus, these results suggest that a deficit in means-end skill is not the exclusive problem for infants in searching for hidden objects. These findings make a significant contribution to the debate about infants' search limitations by providing more evidence regarding the puzzle of why infants fail to search for objects hidden by occluders before 8 to 10 months when they seem sensitive to hidden objects months earlier. Even when means-end task demands were equated by being removed from, or at least diminished in, both hidden and visible conditions in Phases 1 and 2, 6-month-old infants engaged in significantly less manual search with hidden objects than with visible objects. In contrast, there were no significant differences among 10-month-old infants. This pattern of results indicates that object visibility significantly affects 6-month-old infants' behavior. The results are analogous to those of other studies equating means-end demands for hidden and visible events: From 5 to 8 months, infants succeed more with visible objects and show little sensitivity to hidden objects (Bower & Wishart, 1972; Gratch, 1972; Munakata et al., 1997; Neilson, 1982; Shinskey et al., 2000). In combination, this collection of results raises the question of whether reliance on a means-end deficit account is necessary to explain infants' search limitations.

What implications might these results have for interpretations of violation-of-expectation studies? Some indirect implications may be drawn from infants' looking behavior in the present experiment, which investigated infants' visual attention to occlusion events, in addition to assessing manual search. If infants' knowledge can be inferred from their looking behavior on possible and impossible occlusion events, then why does their looking behavior in this experiment appear inconsistent with the idea that they are sensitive to hidden objects?

Ten-month-old infants showed the same degree of visual attention on visible and hidden events. In contrast, 6-month-old infants differed on measures of visual attention. When the object was hidden rather than visible, their first look was shorter, their first look away was longer, and they spent more of the trial looking away. There was no evidence to suggest that looking variables were more sensitive measures of the 6-month-old infants' knowledge than manual search measures were. In conjunction with the results of other studies that failed to find sensitivity to hidden objects with looking measures (e.g., Bogartz, Shinskey, & Schilling, 2000; Cashon & Cohen, 2000; Rivera, Wakeley, & Langer, 1999; Schilling, 2000; Shinskey et al., 2000; but see also Aslin, 2000; Baillargeon, 2000; Munakata, 2000), the study presented here also does not show evidence that infants' looking behavior reflects sensitivity to hidden objects. However, neither the events nor the dependent measures used here are the same as those used in the violation-of-expectation paradigm, which moderates the comparison.

What implications do these results have for reaching-in-the-dark studies, which support the means-end deficit account? In both the approach presented here and the reaching-in-the-dark paradigm, infants receive search tasks in which an object could be retrieved with a direct reach rather than a means-end sequence. However, different interpretations have resulted. The results discussed here suggest that infants are not more successful at retrieving hidden objects when there are little to no means-end demands. In contrast, the conclusion of reaching-in-the-dark studies has been that infants are more successful when there are no means-end demands. Why is there a difference? Perhaps another account better explains results from reaching-in-the-dark studies than a means-end deficit account does. For example, according to the graded representations account, infants' representations of hidden objects gradually strengthen with development to support success on a greater range of tasks (Munakata et al., 1997). This account is consistent with infants' sensitivity to hidden objects around 3 to 4 months in violation-of-expectation studies, between 5 and 7 months in reaching-in-the-dark studies, and between 8 and 10 months in means-end search tasks. Perhaps infants' representations between 5 and 7 months are strong enough to support search in the dark, but not in means-end tasks in the light (Munakata, Jonsson, Spelke, & von Hofsten, 1996). The absence of all visual input (i.e., global darkness) may interfere less with a fragile representation than the sight of an occluder in the place where the infant just saw the object. That is, distraction by what is in sight in a lighted room may prevent infants from revealing the sensitivity to hidden objects that seems more evident when tested in the dark. Preliminary supporting evidence shows that 6-month-old infants reached more often for a hidden object when occlusion consisted of either darkness alone or darkness plus a screen, than when occlusion consisted of only the screen in the light (Munakata & Stedron, 2002).

What other explanations, in addition to the means-end deficit account and the graded representations account, have been proposed to account for both infants' sensitivity to hidden objects in some paradigms and for their problems in searching for objects hidden by occluders? The finding that object visibility had a significant effect on 6-month-olds but not 10-month-old infants' search is consistent with several explanations. The results are consistent with the idea that infants may not fully understand the concept of object permanence before about 8 to 10 months (Piaget, 1952, 1954). For example, 6-month-old infants were fairly successful in retrieving fully visible objects and partly visible objects, but less successful in retrieving fully hidden objects. In contrast, 10-month-old infants' search was not affected by object visibility. However, the fact that 6-month-old infants ever contacted or retrieved a hidden object suggests they may not be as unaware of the object's presence, as might be surmised from Piaget's (1952, 1954) account. In combination with the literature on infants' sensitivity to hidden objects in the violation-of-expectation paradigm (e.g., Baillargeon et al., 1985) and the reaching-in-the-dark paradigm (e.g., Clifton, Rochat, et al., 1991; Hood & Willatts, 1986), these results pose a problem for a Piagetian account.

A host of other explanations may also account for infants' differential successes and limitations with hidden objects. One idea is that early preferential looking in violation-of-expectation studies may reflect simpler processes than knowledge that the object still exists (Bremner, 1998; Meltzoff & Moore, 1998). For example, the results may be explained more simply by infants' tracking of the identity of an object—a process they are capable of before they know or reason about permanent objects (Meltzoff & Moore, 1998). In contrast, it has been suggested that the representation of object identity develops relatively late, compared to the representation of object location (*object indexing*) and that this difference accounts for the developmental lag (Leslie, Xu, Tremoulet, & Scholl, 1998). A similar account suggests there is a lack of coordination of information about object identity with information about object position (Mareschal, Plunkett, & Harris, 1999). That is, looking behavior may be driven by information about object position rather than object identity, whereas manual retrieval may require the coordination of both sources of information (Mareschal et al., 1999). Whether these types of representations are fundamentally different, or whether one is an earlier form of the other on a continuum of representations is unclear (e.g., Munakata et al., 1997; Spelke, 1994; Spelke, Katz, Purcell, Ehrlich, & Breinlinger, 1994). In general, however, the suggestion is that an early-developing representation may support success on visual tasks, whereas a later-developing representation may support success on search tasks (Bertenthal, 1996; Diamond, 1998; Munakata & Stedron, 2002; Schacter & Moscovitch, 1984; Spelke, Vishton, & von Hofsten, 1995).

Although the results presented here indicate that a means-end skill deficit is not the only cause of infants' search limitations, no claim is made that means-end skill is fully established or that it does not continue to develop with age. Infants continue to gradually develop in their means-end ability, which they use spontaneously by about 8 to 10 months (Diamond, 1991; Willatts, 1985)—about the same age that they also begin to search consistently for hidden objects. However, a means-end deficit does not appear to be the *only* cause of infants' search limitations. Perhaps several capacities that develop around the same time are ultimately responsible for infants' improved search skill, including reaching skill, problem-solving ability, memory, and spatial knowledge. What research might follow from this experiment to move the field forward? The many recent explanations for the difference between infants' performance on violation-of-expectation tasks or reaching-in-the-dark tasks and manual retrieval tasks described here are currently under investigation in several laboratories. These accounts each have different implications for the nature of early cognitive development. The hope is that future research will increase our understanding about the origins and development of infants' knowledge and provide a coherent theory that explains both infants' successes and limitations.

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