Some things never change: Object occlusions and predictive reaching in infants and adults

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Abstract

Infants can anticipate the future location of a moving object and execute a predictive reach to intercept the object. When a moving object is temporarily hidden by darkness or occlusion, 6-month-old infants' reaching is perturbed but performance on darkness trials is significantly better than occlusion trials. How does this reaching behavior change over development? Experiment 1 tested predictive reaching of 6- and 9-month-old infants. While there was an increase in the overall number of reaches with increasing age, there were significantly fewer predictive reaches during the occlusion compared to visible trials and no age-related changes in this pattern. Experiment 2 tested adults with a similar reaching task. Like infants, the adults were most accurate when the target was continuously visible and performance in darkness trials was significantly better than occlusion trials, providing evidence that there is something specific about occlusion that makes it more difficult than merely lack of visibility.

Key words: occlusion; infancy; reaching

Occlusion happens. Whether you are searching for keys in a cluttered room or trying to track a ball while it passes behind your tennis partner, we are often maintaining expectations about objects that are temporarily hidden. Tracking objects during temporary occlusion is a universal problem not specific to age, SES, culture, or gender. There are two mountains of evidence concerning the tracking of occluded objects over development and surprisingly they point in opposite directions.

One set of findings suggests that the fundamental ability to track occluded objects is evident in infancy and continuous through development. Two-month-old infants have expectations about the location, solidity, and persistence of hidden objects (Aguiar & Baillargeon, 1999; Hespos & Baillargeon, 2001; Spelke, Breinlinger, Macomber, & Jacobson, 1992). Adults have the ability to track multiple objects even when they become occluded (Scholl & Pylyshyn, 1999). Tracking occluded objects is not specific to humans. Non-human primates are able to track the number, location, and trajectory of hidden objects (Filion, Washburn, & Gulledge, 1996; Hauser, MacNeilage, & Ware, 1996; Santos, 2004). These findings suggest that the essence of tracking occluded objects is evident early, shared among other species, and the developmental changes are processes of elaboration and refinement.

Experiments on object perception support this view and lend insight to the nature of the underlying mechanism. Object perception has been well studied at the behavioral level in infants over the past 20 years (for reviews see, Baillargeon, 2004; Kellman & Arterberry, 1998; Spelke & Newport, 1998). This research has charted the developmental time course of a variety of central aspects of object perception including figure-ground organization (Termine, Hrynick, Kestenbaum, Gleitman, & Spelke, 1987), object and face discrimination (Bushnell, Sai, &

Mullin, 1989), size and shape constancy (Slater, Mattock, & Brown, 1990), perception of shape over changes in location and size (Milewski, 1979), perception of partly occluded forms and objects (Kawabata, Gyoba, Inoue, & Ohtsubo, 1999; Kellman & Spelke, 1983) and categorization of objects into domains such as faces, animals, and artifacts (Mandler, 1992; Quinn & Eimas, 1998). In all these cases, studies of young infants (birth – 3 months) have found evidence for perceptual abilities that resemble those of adults. Moreover, studies of older infants have found progressive changes in the efficiency and sensitivity of their perceptual processing. The general conclusion gleaned from these studies is that the signatures of the infant and adult object perceptual systems are similar, therefore it suggests that there is a common underlying mechanism guiding behavior in these instances.

While the findings described above portray continuity in object processing through development, there is a different mountain of evidence that suggests discontinuity in tracking occluded objects. Action tasks often yield contrasting results about the development of tracking occluded objects in that infants fail to retrieve hidden objects until about 9 months of age (Diamond & Lee, 2000; Piaget, 1954). Moreover, children perform surprisingly poorly on manual object search tasks that were modeled after looking time studies. For example, 2-year-old children viewed a ball rolling down a ramp toward a barrier. The ramp was mostly hidden behind a screen with 4 doors that could be opened to access the ball where it stopped against a barrier positioned on the ramp. The toddlers were encouraged to retrieve the ball by opening one of four doors in the screen. Surprisingly, toddlers choose among the doors at random, apparently oblivious to the relations between the ball, ramp, and barrier (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000). This robust finding has been replicated numerous times in experiments that vary the direction of motion (e.g., vertical, left, and right)(Hood, Carey, & Prasada, 2000;

Powell, Berthier, & Moore, 1979), use a transparent screen so that the children could see the object traverse between each door (Butler, Berthier, & Clifton, 2002), measure the amount of visual tracking during performance (Mash, Keen, & Berthier, 2003), and vary the proximity of a visual cue that reminds the participants where the object is located above the screen (Shutts, Keen, & Spelke, 2006). Toddlers' failures to perform a successful reach were especially striking because two additional studies confirmed that, like infants, toddlers looked longer at an event that revealed the ball in an impossible position (Hood, Cole-Davies, & Dias, 2003; Mash, Novak, Berthier, & Keen, 2006).

If we evaluate the ability to track hidden objects solely on reaching behavior, then it appears that there are qualitative differences in the cognitive capacities of children and adults. Data from these action tasks depict tracking occluded objects as having a protracted development that does not exist for most of the first year and is a fragile and incompetent system for toddlers. Taken together, these reaching studies portray discontinuity in how infants and adults represent occluded objects.

The present research

These apparently inconsistent findings are puzzling in light of the fact that visual tracking and reaching for objects appear to require the same knowledge. Standing in the valley between these two mountains of evidence about tracking objects we ask: Why do infants do so badly at Piaget's search tasks? Why do toddlers do so badly at retrieving a toy rolled down a ramp? Either there are qualitative changes in action capacities, or discontinuous shifts in central executive processes underlying the decision to reach for objects that become occluded. The present experiments distinguish these possibilities by presenting a reaching task that requires processing of occluded objects but does not require execution of a complex motor response. We present this task to infants who straddle the ages over which Piagetian search tasks reveal developmental discontinuities. In addition, we also tested adults who are well beyond the age of the discontinuous changes found in children. By looking at the developmental changes across ages, we aim to shed light on the changes in the underlying mechanism of object tracking and predictive action. If there is a dramatic improvement in reaching for an occluded object, relative to reaching for a visible object between 6 and 9 months of age, that finding would suggest that infants and adults process these events in qualitatively different ways from younger infants. However, if young infants' difficulty with occlusion trials is reproduced at 9 months and in adults, that finding would support the view that common mechanisms of object representation are preserved across development and are perturbed by occlusion at all ages.

In these experiments, we used a predictive reaching task. Von Hofsten (1980) was the first to show that young infants reach predictively for moving objects. When a continuously visible, out-of-reach object begins to move smoothly toward them, infants as young as 4 months typically will attempt to grab it, initiating their reach before the object enters their reaching space and aiming ahead of the object's current position so as to intercept it when it comes within their range (von Hofsten, 1980; von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998). Spelke and von Hofsten (2001) placed an occluder over a portion of the object's path on some trials, such that the object moved briefly out of view before it entered infants' reaching space. They found that the presence of the occluder interfered with young infants' ability to reach. Because the occluder was out of reach, it did not serve as a physical barrier to infants' reaching - infants could catch the object by carrying out the same direct, predictive reach as the trials on which the object was fully visible. The occluder therefore prevented infants from seeing the object but did not affect the motor actions needed to retrieve the object. Infants' head tracking in trials with the occluder suggested that they represented the hidden object because their head moved in anticipation of the object emerging from the other side of the occluder (Jonsson & von Hofsten, 2003; Spelke & von Hofsten, 2001). The authors speculated that occlusion reduced the precision of infants' representation of the object, and that it impaired predictive reaching more than looking because reaching for an object requires a more precise representation of its location, properties, and motion.

To investigate whether this pattern is preserved over development, we replicated these experiments with young infants and extended them to older infants and adults.

Experiment 1

Infants aged 6 and 9 months were seated in an infant seat in front of a large white board. A small toy with a rattle inside was given to the infants to explore. After a short time, the toy was taken and placed on the board out of the infants reach. The infant's attention was drawn to the toy and the toy moved in a diagonal, linear trajectory across the infant's reaching space in the fronto-parallel plane. The object came within reach during a short period when it was right in front of the infant. The infants were encouraged to reach/catch the moving object and remove it from the board. The experiment included 24 trials of object motion. Predictive reaching was measured. During the first and last 6 trials, baseline reaching activity was established when the object was visible throughout its motion. During the 12 middle trials, the object was temporarily hidden during an interval before it came within reach by moving behind an occluder. The interval of non-visibility was 600 ms. The rationale was if there is discontinuity in infants' action capacities when an object becomes temporarily occluded, then the older infants should show improved performance in occlusion trials relative to the younger infants. However, if failures in reaching performance are due to the nature of the representation then both age groups will have fewer predictive reaches on trials with occlusion

Method

Participants

Fifty-four infants participated in the experiment. The children were recruited by mail and came from surrounding areas. The parents were offered $5 reimbursement for their travel expenses. To be included in the final analysis of the experiment, the infants needed to be alert and interested in the object throughout the 24 trials. Infants that displayed active responses such as reaching for the toy were defined as being alert and interested. Altogether, 30 infants, (13 male, 17 female) fulfilled this criterion and the analyses are based on them. There were 13 6-month-olds (range = 6 months, 8 days to 7 months, 2 days, *M* = 6 months, 20 days), and 17 9-month-olds (range = 8 months, 11 days to 10 months, 20 days, *M* = 9 months, 11 days).

Display and apparatus

To be able to produce linear motion on a relatively large surface with precision, we used a computer-controlled plane plotter (Roland DPX-4600) whose pen was replaced with a small magnet (von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998). The plotting area was topped with a sheet of aluminum that was painted white, coated with a silicone lubricant and placed on a supporting structure such that it tilted 15 degrees forward from the vertical position. The aluminum sheet served as the background for an object, which was supported by a 10 cm wooden dowel rod firmly attached to a second magnet. When the magnet on the object’s supporting rod was placed on the aluminum sheet directly over the plotter magnet, the combined attraction held the object in place and caused it to undergo whatever motion was produced by the plotter. By using the commands originally intended to direct the motion of the plotter pen, this apparatus enabled us to direct the motion of any small object very precisely, anywhere along the surface of the plotter.

The objects always moved in a linear diagonal path with constant velocity (30 cm/s) from the infant's upper left to their lower right. The object passed behind an occluder positioned to the side of the infant in such a way that it always became visible again at the same position. The occluder was a tunnel made out of black foam core. It was 15.8 cm wide, 9.4 cm long, and 15 cm from the board. The right edge of the occluder was positioned 6 cm to the right of the left armrest of the infant chair so that the bottom part of the object became visible at the armrest. The object presented was a toy bear, approximately 12 cm in height and 5 cm wide.

Design and procedure

The experiment was divided into 4 blocks, each consisting of 6 trials. During the first and last block (Blocks 1 and 4) the object was fully visible all the time. For the two middle blocks (Blocks 2 and 3) the object was occluded during part of its motion.

When parents arrived with their child, the procedure was explained to them and they signed a written consent. The infant was given several minutes to play with the experimental object and to become accustomed to the new surroundings. The infant was placed in a standard infant chair (Mothercare Inc.) approximately 25 cm from the white screen of the plotter, and the object was positioned on the board directly in front of the infant. In order to make the task more attractive, the infants were given the opportunity to retrieve the object twice before the experiment started. The object was then moved to the far upper left position of the screen and the infant’s attention was drawn to the object, after which the experimenter stepped back and pressed a computer key to initiate the object’s motion.

During the experiment the object always started out of reach in the upper left corner with respect to the infant’s midline. The object moved down and to the right on a diagonal trajectory and at a constant speed of 30 cm/s (See Figure 1). The motion path was 128 cm long and measured 83 cm in the vertical dimension and 97 cm in the horizontal dimension. The periods of non-visibility by occlusion started approximately 44 cm into the trajectory. They always became visible again after 18 cm of occlusion. The object passed in front of the infant’s midpoint 64 cm into the trajectory. The pink portion of the picture represents the infant’s reaching space. The black portion represents the occluder. The linear trajectory ended 64 cm from the infant’s midline and the toy circled back to the starting position traveling the dotted path on the perimeter of the white screen. If the infant retrieved the object during its rightward motion, it was gently removed from the infant’s hand and manually repositioned at the same starting position. The plotter made a noise during motion but this noise did not originate from the moving object but rather from the stationary motors of the plotter. It was not possible to determine the position of the moving object from the noise made by the plotter.

Coding equipment

As a reach takes at least 300 ms to prepare (see von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998) and at least another 300 ms to carry out, reaches arriving at the object on the left side of the midline had to be planned before the object reappeared. A predictive reach was coded when the hand came within 7.5 cm of the object in all three dimensions of space for at least one frame during the period from when it had reappeared in the occlusion conditions until it passed the midline. For the purpose of comparison, the same criteria were applied when coding reaches in Block 1 and 4 where the object was continuously visible.

For coding purposes, two circles with their centers marked were drawn on a sheet of transparent plastic. The radius of the circles corresponded to 7.5 cm in each of the two video projection planes (lateral and sagittal) and when the hand was within both of these circles it was closer than 7.5 cm in all dimensions of space. To judge whether a reach was within 7.5 cm of the object in each of the two projection planes, the plastic sheet was placed over the video screen with the center of the appropriate circle positioned at the center of the object seen on the video. If the hand was within the circle on each of the video projections, a reach was coded. All trials were coded by two people. Cohen's kappa was found to be .92.

Results

The data were analyzed by analysis of variance (ANOVA) with the within-subject factors of condition (visible or occluded) and block (first or second) and age as a between-subject variable (6 or 9 months). The analysis revealed a significant main effect for condition (F (1,28) = 21.87, $p < .001$) demonstrating that infants made more predictive reaches during visible (M = 3.05) compared to occluded (M = 1.78) trials (See Figure 2). The interaction between condition and age was not significant (F(1, 28) < 1) suggesting that there were no significant differences in how infants reacted to the visibility across ages (See Figure 3). Finally, there was a significant main effect of age (F(1, 28) = 8.63, $p < .01$) suggesting that as infants got older they reach more often regardless of condition (M for 6 months = 1.52, M for 9 months = 3.10). Examination of the participants' individual responses revealed that 22 out of 30 infants had more predictive reaches during the visible than the occluded trials (cumulative binomial probability, $p < .01$).

Further analysis revealed that the pattern of decreased reaching during the occluded compared to the visible trials was upheld in each age group independently: for 6-month-olds F(1,12) = 9.67, *p* < .01, for 9-month-olds F(1,16) = 13.41, *p* < .01.

Discussion

There were two main findings from this experiment. First, there was a significant increase in the number or reaches over development. Regardless of whether the object was visible or occluded, 9-month-old infants reached significantly more often than 6-month-old infants. This increase in performance could be due to advances in motor competence and/or enhanced representational abilities that develop between 6 and 9 months of age. The second main finding was that as a group and as individuals, infants showed a significant decrease in reaching during occlusion trials. More specifically, increases in age led to an increase in the number of predictive reaches, but the influence of occlusion remained constant. These data allow for a distinction to be drawn between general improvements in reaching (e.g., that 9-month olds reach more often than 6-month olds) and occlusion effects (e.g., that there is significantly less reaching during occlusion compared to visible trials).

These findings suggest that the nature and limits to object representations are similar for 6- and 9-month-old infants in that occlusion disturbs the ability to perform a predictive reach. Our findings replicate and extend research by Spelke and von Hofsten (2001) and Jonsson and von Hofsten (2003) who tested 6-month-old infants. Furthermore these findings complement the research from Gredebäck and von Hofsten (2004), who found similar limitations in predicting high velocity movements (linear decrease with increasing velocities) at all ages. Their data suggests that infants between 6 and 12 months of age suffer the same limitations when predicting the trajectory of occluded objects and that observable differences were related to an overall increase in representational abilities.

The hypothesis that infants' object representations are more precise when objects are visible than when they are hidden could explain why infants reach predictively for moving, visible objects and look predictively at moving, temporarily occluded objects, but fail to reach predictively for moving, temporarily occluded objects. To catch a moving object, one must represent considerable information about the object, including its size, shape, path, and speed of motion. When the object is continuously visible, infants' representations evidently are adequate to guide appropriate reaching. When the object is hidden, however, their representation of its properties may become too imprecise to guide effective attempts to intercept it. However, even an imprecise representation of an occluded object may suffice to guide a look in the correct direction.

One problem with the visibility hypothesis is that it cannot explain why infants' reach more often for objects in the dark compared to objects that are occluded. Jonsson and von Hofsten (2003) compared infants' predictive reaching for objects that were hidden by darkness or occlusion for different durations of time. The experiment revealed three effects. Infants reached most frequently and accurately when the object was continuously visible. Second, reaching was more impaired by longer than by shorter periods of hiding. Both of these findings are consistent with the visibility hypothesis. Third, reaching was more impaired by occlusion than by darkness. One way to account for these results is to add a caveat to the visibility hypothesis: representations of objects are more precise when no other objects compete for attention (Jonsson & von Hofsten, 2003; Munakata & Stedron, 2002). When an object is hidden behind an occluder, it may suffer a double loss of precision due both to its lack of visibility and to competition from its visible occluder. In contrast, an object that vanishes into darkness suffers a loss of precision only because of its lack of visibility and so should be represented more precisely than an occluded object, though less precisely than a visible one.

Experiment 2

The visibility and competition hypothesis are likely to apply not only to the object representations formed by infants but also to those formed by adults. To test whether loss of visibility and competition impairs the precision of object representations throughout development, we conducted an experiment on adults, modeled on the studies of predictive reaching in infants. Participants aimed for an object under 3 conditions in which the object was continuously visible, hidden by darkness, or hidden by occlusion. By presenting the same adults with two manners of hiding the object, we build a bridge to the infant studies where performance in predictive reaching during blackout is significantly better than predictive reaching during occlusion (Spelke & von Hofsten, 2001; Jonsson & von Hofsten, 2003).

The adults stood on the right side of the display used in the reaching studies with infants. Because adults were likely to perform at ceiling on the conditions presented to infants, three changes were made to increase the task difficulty: we doubled the speed of object motion (60 cm/s), increased the duration of interrupted visibility (1 s) and showed a variety of linear trajectories (6). Adults were randomly assigned to one of two conditions. One task involved predictive reaching - to mark a moving *target*, and the other task involved predicting the trajectory of a linear path after viewing only a portion of the *trajectory* (See Figure 4).

In the *target* task, the toy used in the infant studies was replaced with a platform that was parallel to the white board, on the platform we glued a piece of paper that had concentric circles like a bulls-eye target. The participant's task was to stand on the right side of the white board with a pen in hand and view the linear path of the object and tap the target in the center when it reached the right side of the board. The task was challenging because the target was constantly moving and therefore available only briefly. A different color marker was used on each trial and we tallied the amount of ink marks on the target for each condition.

In the *trajectory* task, a separate group of participants were presented with a portion of a linear trajectory and the task was to extend the linear trajectory to the right side of the board and to mark the point at the right edge of the board where the object would intercept the tape stuck to the board. A different color marker was used on each trial and we tallied the distance between the predicted and the actual position of the trajectory.

The rationale for the adult study was if there is continuity in object representation through development, then like infants, adults' performance should be the best in the visible trials, less accurate in the blackout trials, and the least accurate in the occluder trials.

Methods

Participants

The participants were 28 adults 12 male and 16 female (range = 18 years to 43 years, *M* = 22 years). Twelve of the adults were assigned to the *target* condition the remaining 16 were assigned to the *trajectory* condition. Adults were paid $5 for their participation.

Display and apparatus

We used the same apparatus as Experiment 1. The toy that the infants reached for was replaced with a foam core platform that was attached to a 10 cm wooden dowel. The platform was circular and 11 cm in diameter with concentric circles on it.

The objects always moved in a linear diagonal path with constant velocity (60 cm/s). There were 6 different paths presented in a random order. The first path was identical to the path described in Experiment 1. The subsequent 5 paths had start points on the left side of the board 14, 28, 56, 73, and 83 cm below the original. The endpoints were 14, 28, 56, 73, and 83 cm above the original respectively. Three of the paths started in upper half of the board and ended in the lower half the other three started on the lower half of the board and ended in the upper half. A photo-cell switch triggered the extinction of room light with a timer set to the blackout period. The lights went out instantaneously. The occluder was 86 cm tall and 76 cm wide made out of black foam core. The occluder and blackout portions were set up so that the object became hidden at the exact time and place across conditions so the only difference across these conditions was the manner not the lack of visibility. The period of non-visibility by occlusion started approximately 40 cm into the trajectory. In the *target* condition, there was a 20 cm wide white cloth that was attached to the top and bottom edge of the white board. The participants held the marker in their hand under the cloth so that they were forced to rely on the visible portion of the trajectory not the endpoint on the right side of the board. (Pilot studies revealed that performance without the white cloth was at ceiling.) The target was under the white cloth and hence available to marking for 600 ms. In the *trajectory* condition, there was a white piece of masking tape (5 cm wide) affixed to the right side of the board so the participant could mark the tape where they predicted the linear trajectory would intercept. The tape was replaced after each condition to ensure that guesses from prior conditions did not influence performance. During the visible trials, the linear trajectory was 64 cm long and the experimenter removed the target as soon as it stopped because pilot studies revealed that performance was at ceiling when the adult saw more of the trajectory.

Design and procedure

The experimental design was the same for the target and trajectory conditions. Each adult did 36 trials. The experiment was divided into 3 conditions (visible, blackout, and occluded), each consisted of 6 different trajectories. There were 2 blocks of trials. The order of the 6 trajectories was randomized across participants and conditions. After the first 18 trials, the trials were repeated in reverse order. During the first and last block (Blocks 1 and 6) the object was fully visible all the time. For the remaining blocks (Blocks 2 through 5) the object was hidden during part of its motion either by blackout or occlusion. The presentation of the two hidden conditions was counterbalanced across subjects.

Coding

For the *target* condition the coding was simply a tally of the amount of pen marks on the target across conditions. For the *trajectory* condition the coding was a measurement of the absolute distance between the mark on the tape and the correct intercept. The absolute difference did not take into account whether the mistake was above or below the correct location. All of the coding was verified by a second person independently and discrepancies were coded another time until agreement was obtained.

Results

The data from the *target* and *trajectory* conditions were analyzed separately. The *target* data were analyzed by repeated measures ANOVA with within-subject factors of condition (visible, blackout, and occluder) and block (first and second). The analysis revealed a significant main effect for condition ($F(2, 30) = 14.14$, $p < .001$) demonstrating that the most target hits were in the visible condition ($M = 5.22$) followed by the blackout condition ($M = 4.38$) and then the occluder (M = 3.66) condition (See Figure 5). Further t-tests revealed that all conditions were significantly different from each other (visible vs. blackout $t(15) = 5.17$, $p < .001$; visible vs. occluder $t(15) = 3.01$, $p < .01$; blackout vs. occluder $t(15) = 2.40$, $p < .05$).

The *trajectory* data were analyzed in the same manner as the *target* condition. The results were similar across conditions. The analysis revealed a significant main effect for condition ($F(2,22) = 13.27$, $p < .001$) demonstrating that the least amount of error was in the visible condition (M = 5.99), next was the blackout condition (M = 6.71) and the most error was in the occluder (M = 9.39) condition (See Figure 6). The analysis also revealed a significant main effect for block ($F(1,11) = 22.64$ $p < .01$) demonstrating that performance got worse from the first block (M = 6.26) to the second block (M = 8.46). Further t-test revealed that the occluder condition was significantly different from the visible and blackout conditions (visible vs. occluder $t(11) = 4.62$, $p < .001$; blackout vs. occluder $t(11) = 3.65$, $p < .01$). The visible and blackout conditions were not significantly different (visible vs. blackout $t(11) = 1.19$, $p = .26$).

Discussion

There were two main findings from this experiment. First, adults had better performance when the target was visible compared to when the target was hidden for a portion of its trajectory. This finding supports the visibility hypothesis, when an object is continuously visible, the representations are adequate to guide accurate reaching but the precision of the representation suffers when the object is hidden. The second main finding is that there are significant differences in reaching behavior depending on whether the object is hidden by darkness or occlusion. In both the target and trajectory conditions, the performance in the blackout condition was significantly better than performance in the occluder condition. Since the conditions were matched for duration and position the difference in performance must be related to the manner in which the object became hidden. This finding supports the visibility and competition hypothesis, during the occluder condition the representation suffered a double loss of precision due both to its lack of visibility and to competition from the visible occluder. In contrast, the object that was hidden by darkness alone suffered loss of precision only because of its lack of visibility. It is interesting to note, in the trajectory condition that the loss of visibility in the blackout condition was minimal because the performance was not significantly different between the visible and blackout conditions.

General Discussion

The main conclusions from Experiment 1 are that infants between 6 and 9 months of age do not become less affected by the occluder or better able to handle it. The 9-month-old infants did improve in reaching in general, manifested in an overall increase in the amount of reaches. Our data allow us to distinguish between general improvements in reaching from occlusion effects. Experiment 2 complements these results by showing that even adults reveal a disruption in performance during hidden compared to visible trials. Between the two types of hidden trials, adult performance was significantly better in the blackout condition than the occluder condition. These findings suggest that there is something specific about the manner in which an object becomes hidden that predicts performance. Together these findings suggest that infants' and adults' capacities to represent objects are continuous over development, and that the primary developmental changes between infancy and adulthood may concern the precision of the object representations that guide predictive actions.

Our findings accord with the evidence that human infants have a capacity to represent occluded objects as early as two months of age, and that capacity undergoes no qualitative reorganization as children grow. The evidence for ontogenetic continuity complements evidence for phylogenetic continuity in the capacity to represent objects. In particular, non-human primates represent objects similarly to human infants both in preferential looking and in object search tasks (Filion, Washburn, & Gulledge, 1996; Hauser, MacNeilage, & Ware, 1996; Santos, 2004). More dramatically, newly hatched chicks have been shown to pass the object search tasks that human infants fail until nine months of age (Regolin, Vallortigara, & Zanforlin, 1995). These findings make little sense if one thinks that search for hidden objects depends on the construction of a new conception of the world. They mesh well, however, with the view that basic mechanisms of object representation are constant over much of evolution and ontogeny. The expression of object knowledge depends in part on the developing precision of representations and that this development occurs at different rates for different species.

Our findings also accord with the analyses of predictive reaching of von Hofsten and his collaborators (Gredebäck & von Hofsten, 2004; Jonsson & von Hofsten, 2003; Spelke & von Hofsten, 2001). Indeed, a wide range of studies are consistent with the thesis that object-directed reaching requires precise representations, that the precision of object representations increases with age, and that precision declines at all ages when objects are out of view (the visibility hypothesis) and when other objects compete for attention (the competition hypothesis). Because infants’ actions on objects do change over development, the thesis that infants have a constant capacity for object representation requires that one distinguish competence from performance and analyze the factors that limit infants’ performance at young ages. The present findings suggest that visibility and competition are important factors in performance for infants as well as adults.

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Acknowledgements: This research was supported by grants from NIH to the first (HD-08124) and fourth authors (R37-HD23103). We would like to thank the parents of the infants and the adults who participated in this study. We thank Kirsten Condry for help in getting the machinery and software to cooperate. We thank the members of the SALLY group for their insightful comments.

Figure Captions

Figure 1: Schematic of the set up used in Experiment 1. The infant seat was centered in front of a large white board. The yellow circle signifies the toy. The solid line is the toy trajectory during the trial and the dotted line was the path the object took between trials. The pink shaded region represents the infant's reaching space and the black square represents the size and position of the occluder.

Figure 2: Results from Experiment 1. Average number of predictive reaches during visible (white) and occluder (shaded) trials. Error bars represent standard error.

Figure 3: Results from Experiment 1. Percentage of trials that had predictive reaching during the 4 blocks of the experiment. Block 1 and 4 were visible trials and block 2 and 3 were occluder trials.

Figure 4: Schematic of the set up used in Experiment 2. The adults stood at the right side of the apparatus. The yellow and orange arrows signify 2 of the 6 possible trajectories of the target. The black square represents the size and position of the occluder. The small green boxes above and below the left edge of the occluder were photocells that controlled the lights during the blackout condition. When the toy broke the infrared beam between the boxes the room lights went out instantaneously for 1 s. The white rectangle on the right of the stage represents the white cloth used in the target condition.

Figure 5: Results from Experiment 2 *target* condition Average number of target hits for visible (white), blackout (dots), and occluder (lines) conditions. Higher accuracy let to higher number of hits.

Figure 6: Results from Experiment 2 *trajectory* condition. Average absolute error for visible (white), blackout (dots), and occluder (lines) conditions. Higher accuracy led to lower amount of error.

Figure 1

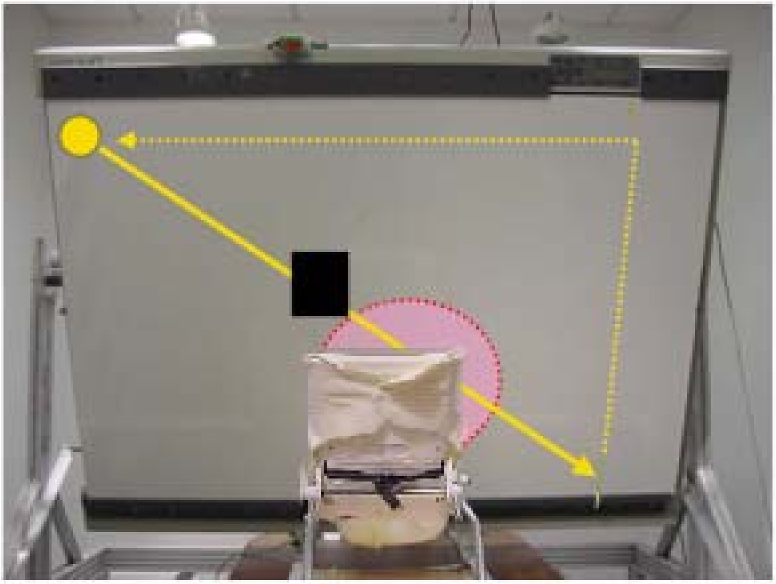

Figure 2

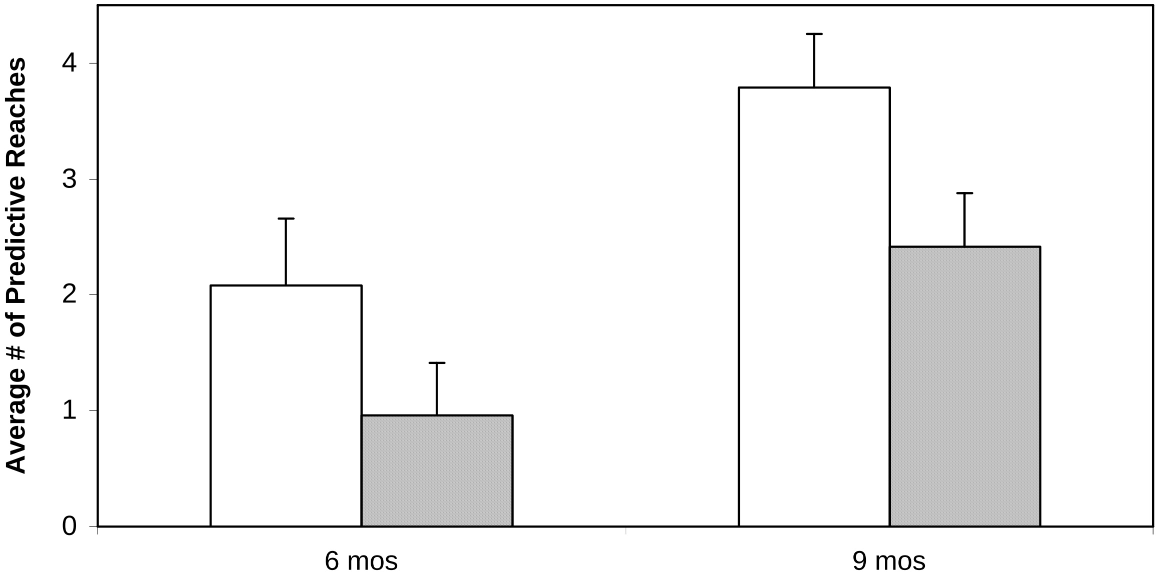

Figure 3

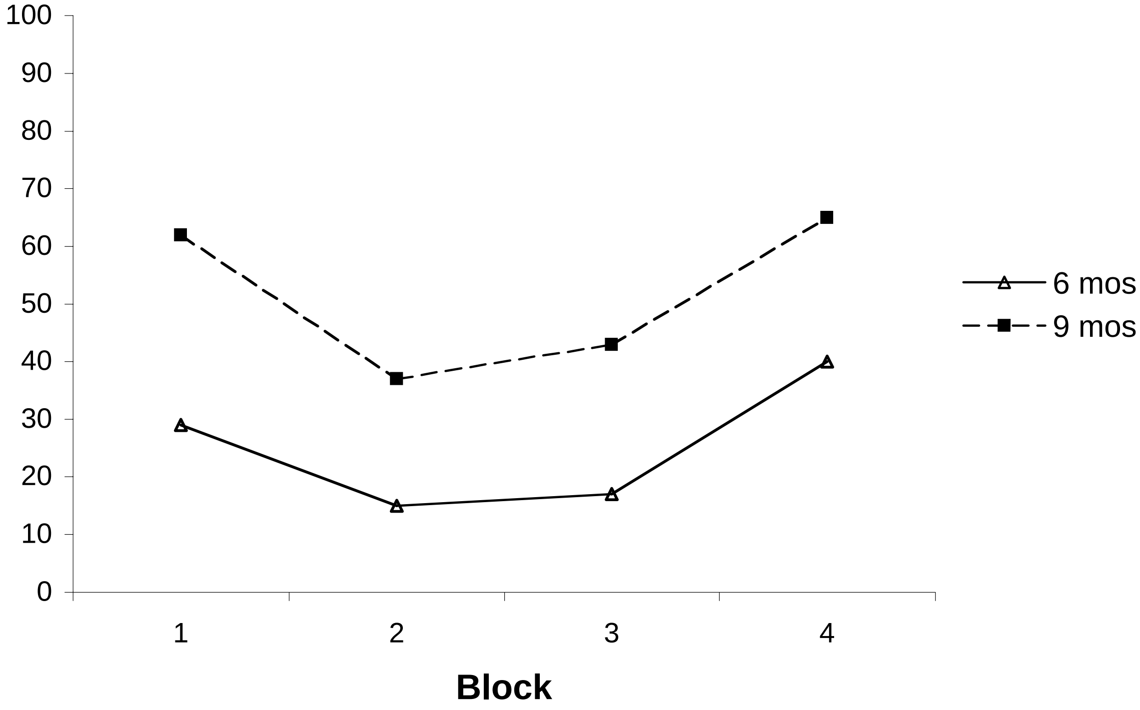

Figure 4

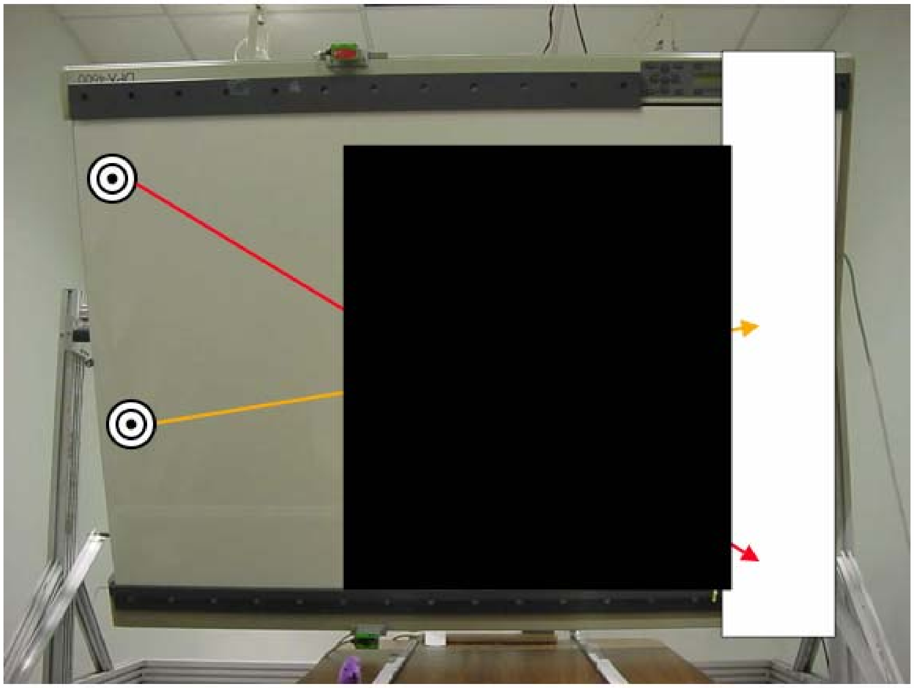

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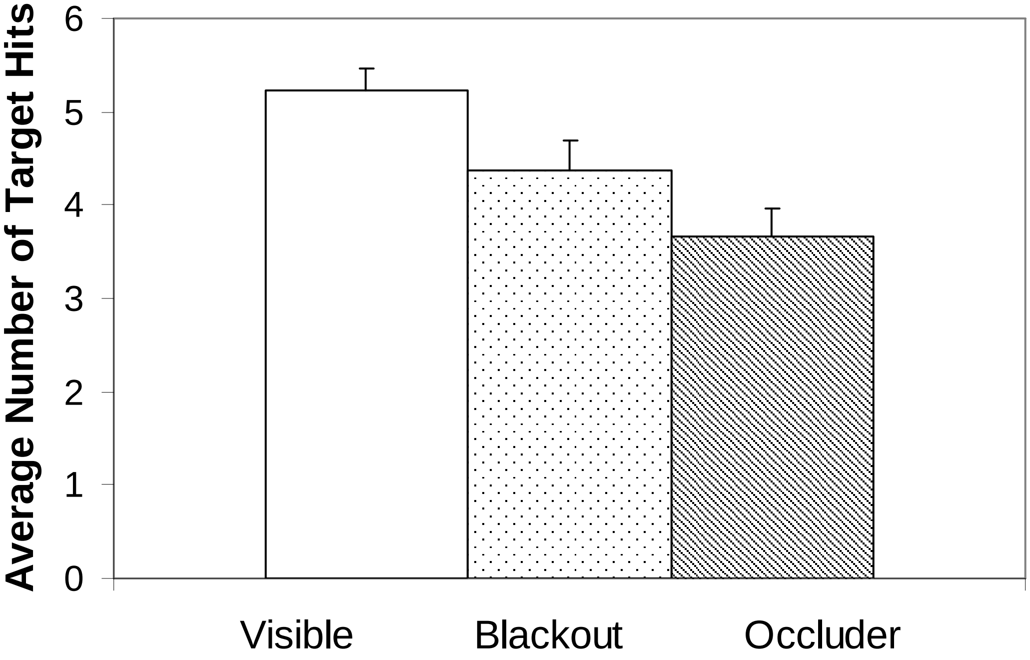
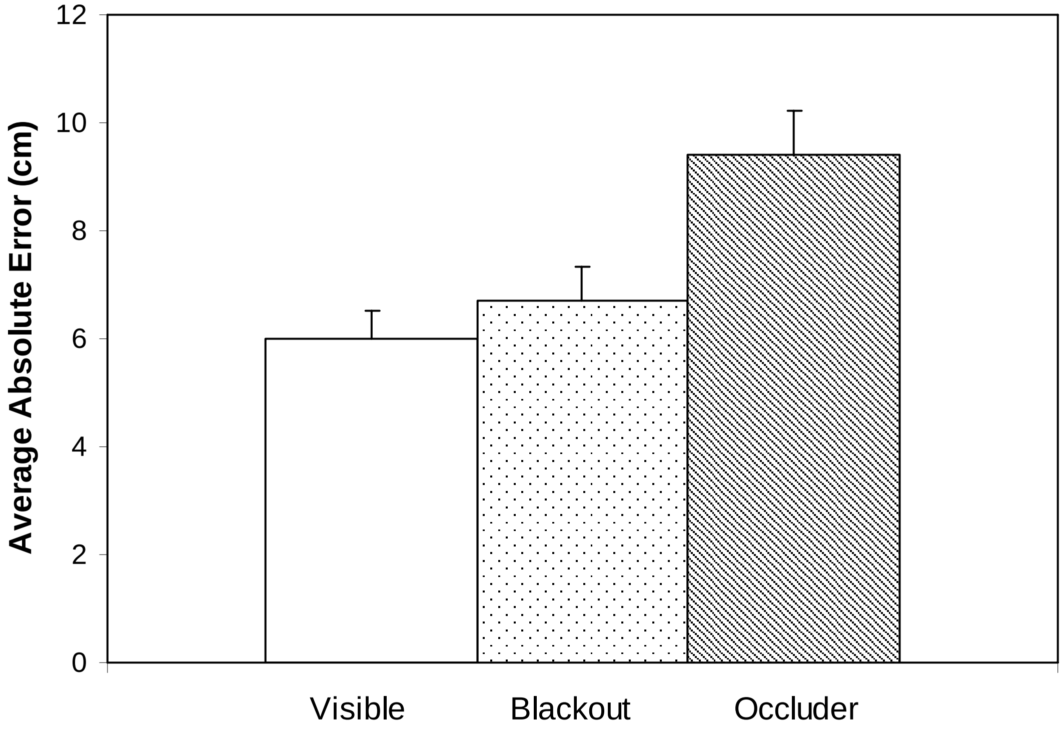
Figure 5



Average Number of Target Hits
6
5
4
3
2
1
0
Visible
Blackout
Occluder

Figure 6



Average Absolute Error (cm)
0
2
4
6
8
10
12
Visible
Blackout
Occluder