Development of object concepts in infancy: Evidence for early learning in an eye-tracking paradigm

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Concepts of objects as enduring and complete across space and time have been documented in infants within several months after birth, but little is known about how such concepts arise during development. Current theories that stress innate knowledge may neglect the potential contributions of experience to guide acquisition of object concepts. To examine whether learning plays an important role in early development of object representations, we used an eye-tracking paradigm with 4- and 6-month-old infants who were provided with an initial period of experience viewing an unoccluded trajectory, or no experience with this particular stimulus. After exposure to the unoccluded trajectory for only 2 min, there was a reliable increase in 4-month-old infants' anticipatory eye movement when the infants subsequently viewed occluded-trajectory displays, relative to 4-month-old infants who did not receive this experience. This effect of training in 4-month-old infants was found to generalize to another category of trajectory orientation. Older infants received no additional benefit from training, most likely because they enter the task capable of forming robust object representations under these conditions. This finding provides compelling evidence that very brief training facilitated formation of object representations, and suggests more generally that infants learn such representations from real-world experience viewing objects undergoing occlusion and disocclusion.

The question of how humans acquire and represent object knowledge is fundamental to cognitive science, and there has been a long standing and relentless debate concerning its developmental origins. These debates have centered on mechanisms of development, which lead infants to view objects as coherent entities that endure across time (i.e., existence constancy), and whose boundaries may extend beyond what is visible directly (i.e., amodal completion; ref. 1). Initial investigations revealed a progression across the first two postnatal years in object-oriented behavior, which was assumed to reflect emergence of object representations from a nascent inability to perceive occlusion (2). On this view, concepts arise from active manual exploration of objects, in particular search for hidden objects, with the advent of reaching and grasping skills at 4–6 months of age. An alternative view emerged from more recent evidence of object representations in infants too young to engage in skilled search, and led to postulates of innate knowledge (3–5). The assumption of this latter view is that, in the absence of evidence to the contrary, functional object representations are rooted in processes that operate independent of experience (6).

A third possibility, which we examine here, is that initial object concepts (i.e., existence constancy) are learned from experience early in postnatal life. We note five lines of evidence that highlight the potential importance of infants' attunement to the visual environment in guiding development of object representations. First, the visual system is organized at birth. Neonates tend to direct visual attention toward areas of high contrast (i.e., edges) and motion, providing suitable conditions for extraction of information specifying segregated surfaces (7). Second, natural scenes are richly structured and characterized by a considerable degree of predictability across space and time (8), and there is evidence that development of response properties of visual neurons exploits the statistical redundancy in the input (9). Third, infants are prodigious learners, responding readily to classical and operant conditioning regimes (10), and exhibiting statistical learning soon after birth (11, 12). Fourth, object concepts arise with the onset of visual experience. Human neonates are not born with the capacity to perceive occlusion, a necessary condition supporting any functional object representation (13, 14). Finally, infants receive an abundance of exposure to the visual environment antecedent to occlusion perception, which has been documented first at 2 months (15). Neonates spend 2–3 h per day in a state of quiet alertness (16), engaging in active scanning of the visual field during the bulk of this time (17). Like adults, young infants produce two to three eye movements per sec (18, 19). Assuming a doubling of the daily duration of alertness by 2 months (20), this result provides the 2-month-old infant with >200 h of visual experience, having executed some 2,500,000 eye movements. Despite these numerous reasons to suspect a strong role for learning in early object concept development, direct evidence has yet to be reported in support of this hypothesis. Obtaining such support for this hypothesis is the goal of this article.

We presented simple object-trajectory displays (Fig. 1) to 4- and 6-month-old infants as we recorded their eye movements with a corneal reflection eye tracker. We reasoned that a representation of the object and its trajectory under occlusion would be reflected in a consistent pattern of anticipatory eye movements toward the place of reemergence, before the object's appearance. We explored three hypotheses. First, we predicted that the older infants would make more anticipatory eye movements than would the younger infants, because 4-month-old infants' object representations under these conditions are fragile, and 6-month-old infants' representations are more robust. In experiments using an habituation paradigm, 4-month-old infants have been found unable to perceive continuity in the occlusion display depicted in Fig. 1. Instead, they responded to visible path segments only, failing to link them into a continuous trajectory. However, 4-month-old infants perceived continuity under less demanding conditions, when occluder size and occlusion time were reduced. Six-month-old infants responded to continuity, even under the more challenging conditions (21). These experiments provide evidence for vital developments in object representations between 4 and 6 months of age, and support the notion that 4 months is a time of transition toward veridical concepts of object continuity. Our second hypothesis concerned the effect of experience on development of continuity perception. We predicted that when provided with initial exposure to an unoccluded trajectory, 4-month-old infants would subsequently produce more frequent anticipations than would 4-month-old infants who received no prior training. Six-month-old infants, in contrast, were predicted to receive no benefit, because they enter the task with a more robust facility to form object representations (21). Our third hypothesis centers on the

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Abbreviations: POG, point of gaze; RT, response time; NS, not significant.

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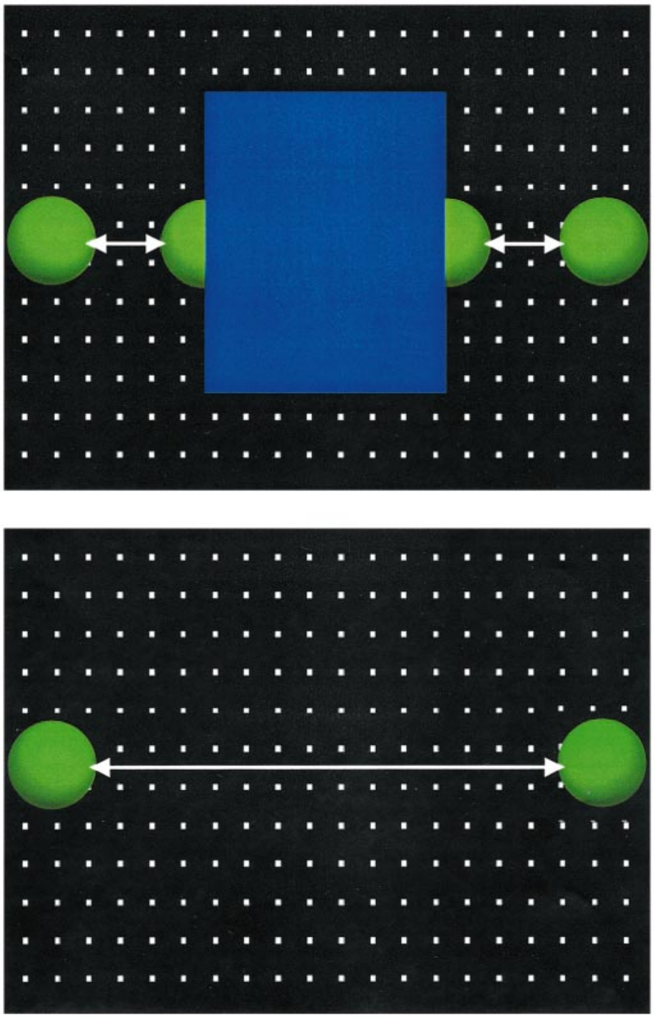

Fig. 1. (*Upper*) The partly occluded trajectory display. A green ball translates repetitively on a linear trajectory, alternately moving behind a blue box and reemerging. Infants in the baseline condition (experiment 1) viewed this display for eight trials, each consisting of six complete cycles of motion. (*Lower*) The fully visible trajectory seen for four trials in the training condition (experiment 2), followed by the partly occluded trajectory display for four trials. Not shown is the fully visible vertical trajectory shown to infants in the training generalization condition (experiment 3), which was identical to the horizontal training condition except for the trajectory orientation.

question of training generalization. We predicted that 4-month-old infants would exhibit facilitation of object concepts even when training and test tasks came from different categories of trajectory orientation. These hypotheses were tested in experiments 1, 2, and 3, respectively.

Experiment 1 establishes any baseline difference between 4- and 6-month-old infants in their ability to anticipate the emergence of a moving object from behind an occluder. Experiments 2 and 3 then determine the role that short-term experience plays in the learning of information about object movement during occlusion. The critical issue is not whether older infants are better at oculomotor anticipation, but whether younger infants who receive brief exposure to unoccluded object movement show subsequent facilitation of anticipation during occlusion, and whether such training can be generalized beyond the original context.

Methods

In all experiments, infants sat in a parent's lap 100 cm from the 76-cm computer monitor used to present the stimuli. Stimuli were prepared by using METACREATIONS INFINI-D 4.0 software, and were presented by using custom software on a G4 Macintosh. Each stimulus consisted of a 30-sec animation depicting a 6.7-cm (3.8° visual angle at the infant's viewing distance) green ball translating laterally across 45.4 cm (25.5°) at 18.2 cm/sec (10.4°/sec). The ball changed direction (left-right) every 2.5 sec. The center of the trajectory was occluded by a 21.5 × 17.7 cm (12.3 × 10.1°) blue box. Ball and occluder were presented against a textured background (a 20 × 12 grid of white dots on black) measuring 48.8 × 33.0 cm (27.4 × 18.7°). In each of the eight trials, a nonrhythmic sound was played to maximize attention toward the stimulus. Each trial had a different sound, and the order of sounds was randomized for each infant. Infants in the training condition (experiment 2) were first presented with four identical stimuli except for the absence of the occluder. (Stimuli used in the habituation experiments described in ref. 21 were identical, except they were silent.) Infants in the generalization condition (experiment 3) were first presented with four stimuli in which the ball translated vertically, rather than horizontally (at the same rate and extent of motion), against the same textured background, with no occluder. Between stimuli an "attention getter" (a target that loomed and contracted in time with a beeping sound) was presented to maintain the infant's interest across trials and recenter the infant's point of gaze (POG). Eye movements were recorded with an ASL model 504 (Applied Science Laboratories, Waltham, MA) remote optics corneal reflection eye tracker. Data (the POG superimposed on the stimuli) were recorded onto videotape and coded offline. Temporal accuracy was determined by the temporal resolution of the videotape system (30 fps; each frame = 33.3 ms).

Each infant's POG was calibrated with a "quick-calibration" routine. Infants were shown the attention getter at the top left and bottom right corners of an imaginary rectangle corresponding to the corners of the stimulus background (the texture elements) viewed during test. The eye tracker interpolated the positions of the remaining calibration points. Calibration was checked by moving the attention getter to random positions on the screen. If the infant's POG was not directed within .5° of the center of the attention getter at all positions (minimum of six), the calibration routine was repeated until this criterion was reached. We estimate therefore that spatial accuracy was at most 1° error, given estimates of the inherent accuracy of the eye tracker provided by the ASL (i.e., an additional 0.5° of error possible).

In experiment 1, infants viewed eight trials of the occlusion display, each with six complete cycles of the object trajectory (12 left-right or right-left excursions per trial, 96 excursions total), as depicted in Fig. 1. In experiments 2 and 3, infants viewed four trials in which the moving object was presented without an occluder, followed by four trials with the occlusion display (48 excursions total). Eye movements were coded for instances of perceptual contact. In each of the 96 excursions from experiment 1 and 48 excursions from experiments 2 and 3, an eye movement was entered into the data set if the infant's POG was directed toward a region of the display within 1.5° (horizontal) and 3° (vertical) of the moving-object trajectory as it was visible on either side of the occluder, after a starting position of the POG outside this region. (Trials in which the POG did not leave the anticipation region across object excursions were not counted, as when infants remained fixated on one or the other side of the display.) Eye movements leading to perceptual contact that were initiated <150 ms subsequent to object emergence were coded as *anticipations*, and those that were initiated later than 150 ms subsequent to object emergence were coded as *reactions*. The 150-ms criterion was derived from past reports of predictive and reactive eye movements in infants (22) and adults (23).

We tested 48 4-month-old infants (mean age = 122.2 days, SD = 10.7; 22 girls and 26 boys) in experiments 1–3 and 32

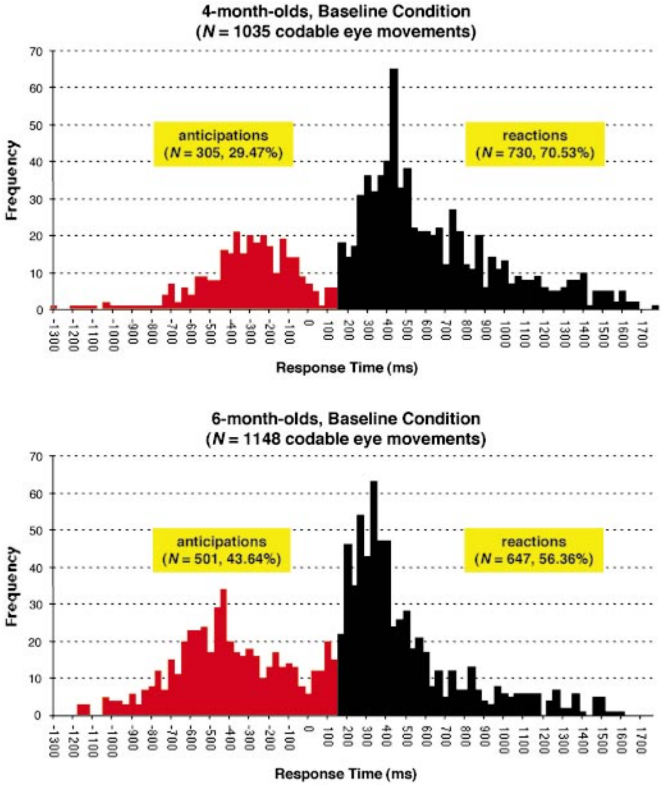

Fig. 2. Histograms of eye movement response times (RTs) relative to the reemergence of the object from behind the occluder (RT = 0). The object began occlusion at −1,300 ms, was fully occluded at −700 ms, was fully visible at 400 ms, and remained visible until 1,800 ms had elapsed. Anticipations are red, and reactions are black. (*Upper*) Four-month-old infants in experiment 1. (*Lower*) Six-month-old infants in experiment 1. The older infants reliably produced more anticipations than did the younger infants.

6-month-old infants (mean age = 185.4 days, SD = 14.4; 19 girls and 13 boys) in experiments 1 and 2. There were 16 infants in each condition. We found no sex differences in performance in any experiment (i.e., proportion of anticipations); all *t* values <1, not significant (NS). All infants were full term and had no known developmental difficulties.

Experiment 1: Baseline Age Differences in Oculomotor Anticipation. Experiment 1 yielded 2,183 eye movements meeting criteria for an anticipation or a reaction: 1,035 from the 4-month-old infants and 1,148 from the 6-month-old infants, representing 67.4% of trials for 4-month-old infants and 74.7% of trials for 6-month-old infants. (Other trials were characterized by missing data or eye movements that did not meet the criteria.) The histograms in Fig. 2 present eye movement frequencies for each age group, plotted as response times (RTs) relative to the emergence of the ball from behind the occluder (RT = 0, the first video frame when the ball became visible). Eye movement latencies tended to cluster into two distributions for both age groups, which were separated by a discontinuity consistent with the 150-ms criterion for classification as an anticipation or a reaction.

Our first prediction was supported. Six-month-old infants produced a reliably higher proportion of anticipations than did 4-month-old infants, $\chi^2 = 46.94$, $P < 0.0001$, providing corroborating evidence for age differences in formation of object representations between 4 and 6 months when viewing occluded-trajectory displays (21). Additional evidence for this suggestion comes from a trial-by-trial analysis of response patterns (Table 1). Anticipations declined across trials for both age groups, $F(7, 210) = 11.73$, $P < 0.0001$, more precipitously in the younger infants, $F(7, 210) = 2.73$, $P < 0.01$, indicating that the infants did not learn to anticipate simply by viewing the repetitive pattern. Past reports of anticipatory eye movements in infancy have found that young infants anticipate repetitive, predictable events on 15–30% of trials, depending on the specific paradigm (22). There are few improvements in anticipation frequency in simple event sequences from 3 to 12 months of age (22), but there are some improvements with age in response to complex sequences (24). In the present baseline condition, which contains a perfectly predictable object movement, the greater proportion of anticipations in the older infants may be taken as evidence for the influence of functional object representations on eye movements.

To further probe the differences in performance as a function of age group, we examined the temporal characteristics of eye movements (Table 2). Older infants were faster overall, including both anticipations and reactions.

Finally, a comparison of the 4-month-old infants' performance to a second group of 16 4-month-old infants (mean age = 126.5 days, SD = 10.0; nine girls and seven boys) who viewed the object moving on a random, unpredictable trajectory revealed no reliable differences in anticipations between the groups, $F(1, 30) = .32$, NS. Infants in the random condition received eight trials with stimuli that were identical to those viewed by infants in the baseline condition except the place of the object's reemergence (left or right) was not predictable from its place of entry behind the occluder; that is, the ball moved behind the occluder and was as likely to emerge from the same side as from the other side relative to the point of entry. An observer would thus be unable to form a representation of a simple, linear object trajectory in this type of display. Infants in the random condition anticipated on 22.46% of trials (SE = 3.36), which is comparable to anticipation performance of the 4-month-old infants in the baseline condition (see Table 1), $t(30) = 0.56$, NS. These comparisons imply that the 4-month-old infants' eye movements that met our criterion for anticipations were more likely to be spontaneous eye movements rather than ''true'' predictions of object emergence.

In sum, a variety of age differences in oculomotor behavior provide evidence of stronger object concepts in 6-month-old infants relative to 4-month-old infants. In particular, the older infants produced anticipations that were both more frequent and faster. Frequency of anticipations in the 4-month-old infant baseline group did not differ reliably relative to the random condition, suggesting that they were unable to capitalize on the visible portions of the trajectory to predict the future position of the object. Therefore, there is little indication that the majority of the anticipations they produced resulted from a representation of the hidden object and its trajectory.

Experiment 2: Effects of Training on Oculomotor Anticipation. In experiment 2, we explored the possibility that incipient object concepts might be facilitated by experience. Four- and 6-month-old infants' eye movements were recorded as they viewed four trials with the occluded-trajectory display used in experiment 1, after first receiving training by viewing four 30-sec trials with an unoccluded trajectory (see Fig. 1). Experiment 2 yielded 1,116 eye movements meeting the criteria described previously; 611 from the 4-month-old infants (79.6% of trials) and 505 from the 6-month-old infants (65.8% of trials; Fig. 3). As in experiment 1, eye movement latencies tended to cluster into two distributions corresponding to anticipations and reactions. In contrast to experiment 1, however, there were age differences in the proportions of the two categories that favored 4-month-old infants, who produced a higher proportion of anticipations, $\chi^2 = 9.78$, $P < 0.01$. Nevertheless, parametric trial-by-trial analyses revealed no significant age differences in performance as a func-

Table 1. Mean trial-by-trial percentages of anticipations and reactions by each age group

	4-month-old infants		6-month-old infants	
Trial	Anticipations, %	Reactions, %	Anticipations, %	Reactions, %
	Experiment 1: baseline condition			
1	32.29 (4.55)	51.04 (5.15)	43.23 (4.89)	41.13 (4.33)
2	29.69 (3.22)	53.64 (3.95)	42.71 (5.31)	45.83 (5.22)
3	20.81 (3.40)	51.56 (4.11)	40.62 (4.86)	47.91 (3.77)
4	20.31 (3.48)	56.26 (4.78)	37.51 (4.23)	36.99 (3.95)
5	14.05 (2.61)	55.20 (5.43)	26.57 (4.18)	33.85 (4.47)
6	18.23 (4.38)	46.88 (4.68)	22.91 (4.72)	42.17 (6.65)
7	16.15 (4.05)	34.89 (5.65)	18.75 (2.58)	50.00 (4.75)
8	9.38 (2.62)	41.14 (6.43)	23.44 (3.16)	41.16 (4.90)
Mean	20.11 (2.47)	48.83 (2.98)	31.97 (1.77)	42.38 (2.45)
	Experiment 2: training condition			
5	43.75 (5.56)	35.94 (5.58)	34.37 (3.39)	48.44 (5.55)
6	38.00 (4.86)	48.44 (5.06)	30.73 (4.42)	42.19 (5.72)
7	36.99 (3.57)	41.15 (4.47)	23.43 (4.18)	47.39 (3.78)
8	27.09 (4.33)	41.16 (4.89)	18.23 (3.82)	41.15 (3.99)
Mean	36.46 (2.88)	41.67 (3.42)	26.69 (2.53)	44.79 (3.52)
	Experiment 3: generalization condition			
5	40.11 (5.03)	35.93 (6.15)		
6	40.62 (5.63)	40.09 (3.89)		
7	39.58 (4.59)	43.34 (5.01)		
8	28.65 (4.30)	31.76 (4.32)		
Mean	37.23 (3.91)	37.78 (3.42)		

Note that these data encompass all trials, not only eye movements that met the criteria for anticipations or reactions, to highlight decreases in response across trials. Numbers do not sum to 100 because on some trials there were no codable eye movements, or eye movements were directed to locations other than the object. Numbers in parentheses are SE.

tion of trial or eye movement category, $F(1, 30) = 3.46$, NS (Table 1). Comparisons of age differences in temporal characteristics of anticipations and reactions revealed that the 6-month-old infants' reactions were faster, but there were no significant differences in timing of anticipations, or overall RTs (Table 2). These results begin to provide evidence that with training, object representations guided eye movement response patterns in the 4-month-old infants.

This suggestion was investigated further with comparisons of data from the first two experiments. We asked first whether the 4-month-old infants' performance in the training condition was similar to that of the 6-month-old infants in the baseline condition; this age difference was not statistically reliable in terms of anticipations vs. responses, $\chi^2 = 0.16$, NS. The difference between the two 4-month-old infant groups, however, was reliable. Infants in the training condition produced a higher proportion of anticipations relative to baseline, $\chi^2 = 47.50$, $P < 0.0001$. A second set of analyses compared timing of anticipations and reactions. Six-month-old infants' reactions in the baseline condition were significantly faster than those of 4-month-old infants in the training condition, $t(30) = 2.69$, $P < 0.05$, but there were no reliable differences in timing of anticipations, $t(30) = 0.81$, NS, nor in mean overall RT, $t(30) = 0.79$ NS. We also compared performance of the two groups of 4-month-old infants. Four-month-old infants' reactions in the training condition were not reliably faster than those of 4-month-old infants in the baseline condition, $t(30) = 0.90$ NS, but anticipations were faster in the training condition, $t(30) = 2.05$, $P < 0.05$, and mean overall RT (which includes both anticipations and reactions) was faster also, $t(30) = 3.98$, $P < 0.001$.

The fact that the 4-month-old infants' anticipatory eye movements occurred more frequently after training suggests that

Table 2. Mean RTs (in milliseconds) of codable eye movements, relative to object emergence

	4-month-old infants	6-month-old infants	Independent samples *t* tests
	Experiment 1: baseline condition		
Anticipations	−297.98 (29.66)	−402.60 (29.92)	$t(30) = 2.48$, $P < .05$
Reactions	675.57 (33.24)	518.00 (22.51)	$t(30) = 3.92$, $P < .001$
Mean	395.65 (35.16)	114.09 (30.48)	$t(30) = 6.05$, $P < .001$
	Experiment 2: training condition		
Anticipations	−391.21 (34.61)	−417.90 (26.57)	$t(30) = .61$, NS
Reactions	631.76 (35.82)	510.92 (46.36)	$t(30) = 2.06$, $P < .05$
Mean	158.95 (47.93)	141.39 (34.05)	$t(30) = .30$, NS
	Experiment 3: generalization condition		
Anticipations	−395.19 (34.33)		
Reactions	603.83 (24.40)		
Mean	108.26 (51.89)		

Numbers in parentheses are SE. NS, not significant.

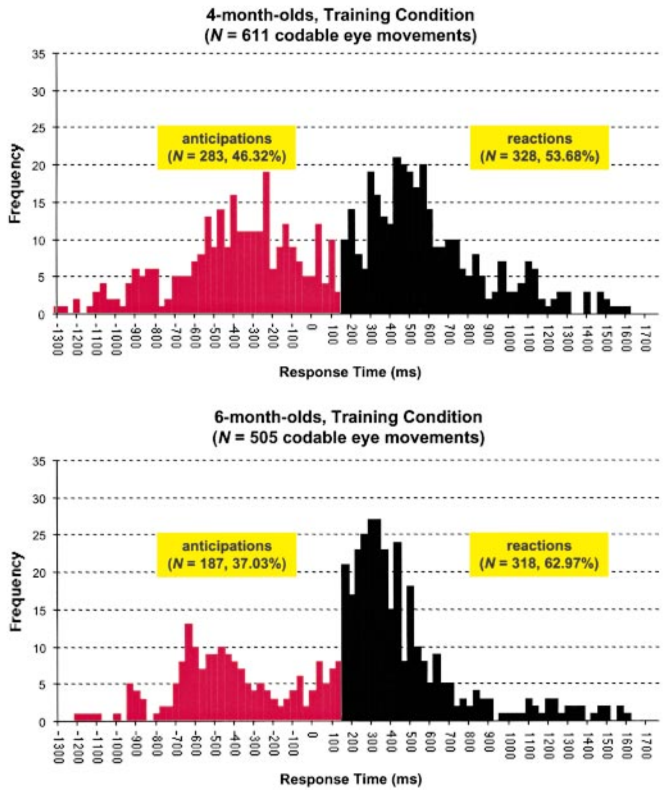

Fig. 3. Histograms of eye-movement RTs in experiment 2. (*Upper*) Four-month-old infants. (*Lower*) Six-month-old infants. Here, 4-month-old infants actually produced a higher proportion of anticipations relative to 6-month-old infants, in contrast to experiment 1 results, implying that functional object representations were facilitated by experience viewing the unoccluded trajectory in the younger infants. Older infants' performance was not improved by experience, implying that they enter the task with the ability to form representations of object continuity under these conditions.

these changes were not simply a matter of the four preexposure trials entraining pursuit eye movements that continued into the four occlusion trials. One possible alternative explanation of this finding stems from the observation that anticipations decrease reliably with repetition. Is the proportion of anticipations higher in the training condition because only *four* training trials are being compared with *eight* baseline trials? An examination of Table 1 reveals that this is not the case. The proportion subsequent to training is greater even if compared with the mean for the first four baseline trials only, $t(30) = 2.70$, $P < 0.05$.

Taken together, these data suggest that object representations directed anticipatory eye movements in the 6-month-old infants and the 4-month-old infants in the training condition, but not the 4-month-old infants in the baseline or random conditions. In particular, comparisons of data sets from the 4-month-old infants in the first two experiments reveal striking differences in performance as a function of training, and support our hypotheses regarding the facilitation of object representations from a short time of experience.

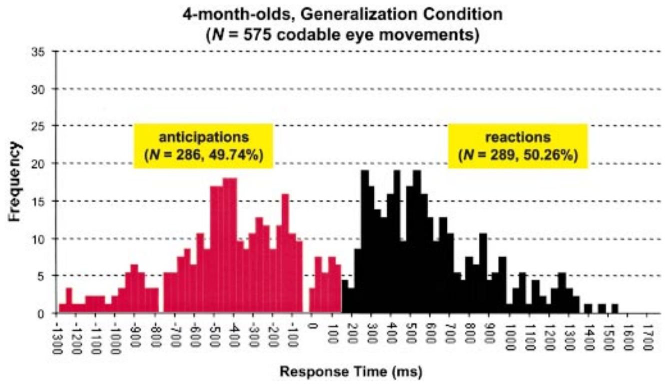

Fig. 4. Histograms of eye-movement RTs in experiment 3. The distribution of anticipations vs. responses is not reliably different relative to the data from 4-month-old infants in experiment 2, but there are significantly more anticipations relative to baseline, and anticipations are faster overall. This finding suggests that 4-month-old infants generalized training from a different trajectory category.

Experiment 3: Effects of Training Generalization on Oculomotor Anticipation. In the final experiment, we asked whether training with a different trajectory event would generalize to improved performance with the test events used in experiments 1 and 2. Four-month-old infants' eye movements were recorded as they viewed four horizontal occlusion trials after seeing four 30-sec trials with an unoccluded vertical trajectory, identical to the training event from experiment 2 (i.e., the same background texture) except for its orientation. Experiment 3 yielded 575 eye movements meeting the criteria described previously (75.0% of trials; Fig. 4). The distribution of anticipations vs. reactions is very similar to that produced by the 4-month-old infants in experiment 2, and indeed, there was no reliable difference in proportions between the two groups, $\chi^2 = 1.39$, NS. Parametric trial-by-trial analyses likewise revealed no significant differences in performance between the two groups, $F(1, 30) = 0.17$, NS (Table 1). A comparison to baseline data from the 4-month-old infants in experiment 1, in contrast, revealed a significantly higher proportion of anticipations after experience with the vertical trajectory, $\chi^2 = 65.37$, $P < 0.0001$.

A final set of analyses examined the temporal characteristics of anticipations and reactions across experiments. Anticipation latencies in experiment 3 were significantly faster than those of the 4-month-old infants in experiment 1, $t(30) = 2.14$, $P < 0.05$, although reactions were not reliably different, $t(30) = 1.74$, NS (Table 2). Comparisons with data from the 4-month-old infants in experiment 2, however, revealed no reliable differences, t values < 0.7, NS. Comparisons of latencies from experiment 3 with data from the 6-month-old infants in experiments 1 and 2, likewise, yielded no significant differences in anticipation latency, t values < 0.6, NS.

The findings from experiment 3 confirm and extend the conclusions reached from the first two experiments. Four-month-old infants' oculomotor anticipations to occluded-trajectory stimuli were facilitated after experience with a preexposure event whose trajectory differed in orientation, suggesting an ability to generalize object concepts across trajectory category. This finding would appear to obviate an alternative account based on expediting a relatively simple motor "habit," such as facilitation of horizontal eye movements.

Discussion

We found that 4-month-old infants who viewed an object moving on a repetitive, center-occluded trajectory provided little evidence of forming or maintaining a concept of the object as enduring across a short time of occlusion. The infants did not show an increase in anticipations, even after dozens of exposures. Six-month-old infants, in contrast, produced a pattern of eye movements consistent with object representations. We found also that 4-month-old infants' oculomotor behavior was dramatically improved if they were presented first with an unoccluded object trajectory for 2 min, providing unambiguous information for the spatiotemporal continuity of the object. These infants produced *more* anticipations, and *faster* anticipations, akin to older infants. This improvement resulted even if the unoccluded trajectory was a different orientation relative to the stimulus viewed at test. Six-month-old infants appeared to receive no additional benefit from such training. This finding suggests that training facilitated formation of object representations in 4-month-old infants, but did little to help 6-month-old infants, who apparently entered the task capable of establishing representations of continuity under the occlusion conditions used in our experiments.

What is the nature of the learning mechanisms that led to success at our task in 4-month-old infants? These mechanisms are unlikely to be centered in simple oculomotor improvements, such as smooth pursuit. Four- and 6-month-old infants will consistently track a small moving target with a combination of saccadic and smooth eye movements, the proportion of the two depending on object speed, age of the infant, and attentiveness (25, 26). Three features of our unoccluded-trajectory displays, however, may have reduced the likelihood that infants engaged in smooth pursuit to track the ball. First, the velocity of the object (10.4°/sec) was high enough to present a challenge to the developing smooth-pursuit system (27). Second, the object moved against a textured background, which tends to inhibit smooth pursuit (28, 29). Third, the object changed direction every 2.5 sec, perhaps making it difficult to predict direction of motion from moment to moment. In fact, we found no instances of smooth pursuit during training. Instead, tracking was entirely saccadic, the infants' POG consistently lagging behind the ball during training. The anticipatory eye movements we observed during the test trials, therefore, were qualitatively different from object tracking during training, the former by definition consisting of eye movements that led, not followed, the object.

We propose instead that the 4-month-old infants in the training condition learned about object continuity with an associative learning mechanism, which provided a representation of the similarity of fully visible and partly occluded object trajectories. This tendency to form associations appears to be robust to category of trajectory orientation. The increase in anticipations that we observed underscores the readiness of this age group to learn object concepts from experience. There are broader implications as well: In addition to highlighting potential contributions of rapid associative learning in 4-month-old infants, our results reveal that representations of object continuity are acquired by 6 months of age in the absence of direct experience with the unoccluded trajectory. Presumably, this occurrence is induced by viewing the many instances of object movement, occlusion, and disocclusion that are part of the natural visual environment. We obtained no evidence that additional experience with such events produces superior performance on our task in 6-month-old infants. By 6 months, then, infants have had sufficient exposure to occlusion over the normal course of development, which provides appropriate experiences to support formation of rudimentary object concepts.

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