Child Development, September/October 2005, Volume 76, Number 5, Pages 1029 – 1043

Conditions for Young Infants' Perception of Object Trajectories

J. Gavin Bremner
Lancaster University

Scott P. Johnson
New York University

Alan Slater
University of Exeter

Uschi Mason
Lancaster University

Kirsty Foster
Manchester University

Andrea Cheshire and Joanne Spring
Lancaster University

When an object moves behind an occluder and re-emerges, 4-month-old infants perceive trajectory continuity only when the occluder is narrow, raising the question of whether time or distance out of sight is the important constraining variable. One hundred and forty 4-month-olds were tested in five experiments aimed to disambiguate time and distance out of sight. Manipulating the object's visible speed had no effect on infants' responses, but reducing occlusion time by increasing object speed while occluded induced perception of trajectory continuity. In contrast, slowing the ball while it was behind a narrow or intermediate screen did not modify performance. It is concluded that 4-month-olds perceive trajectory continuity when time or distance out of sight is short.

In everyday environments, the objects that we encounter frequently pass into and out of sight as our view of them is obstructed by nearer objects, and yet we perceive these objects as enduring entities. Additionally, when objects move, we perceive their trajectories as continuous even though they may be invisible for part of their path of movement. This ability to fill in the gaps in perception is a fundamental aspect of object perception, and important questions arise regarding its developmental origins.

Early work investigating young infants' perception of events in which an object passes behind a screen was framed in terms of infants' knowledge of object permanence. For instance, Bower, Broughton, and Moore (1971) reported that 2-month-olds anticipated the re-emergence of an object from behind a screen, evidence for object permanence. Moreover, they showed tracking disruption (i.e., oculomotor search) when an object emerged from behind a screen too soon, but not when it changed its form behind the screen, and Bower et al. (1971) interpreted this as indicating a difficulty in integrating object movement and object identity. However, other workers have interpreted the findings of tracking tasks more simply, in terms of object identity (Moore, Borton, & Darby, 1978), or prediction of event sequences (Goldberg, 1976). Additionally, a number of investigators failed to replicate Bower's results (Meicler & Gratch, 1980; Muller & Aslin, 1978). It became clear that measures of tracking disruption were unreliable as indicators of object permanence and highly dependent on object movement rate, whether or not the object passed out of sight (Muller & Aslin, 1978). More recently, Mareschal, Harris, and Plunkett (1997) obtained evidence that supports the view that tracking disruption is influenced by low-level factors such as object speed and time out of sight. It is thus evident that, in respect of young infants at least, tracking disruption cannot be relied on as an index of object permanence and although it may well be a useful means of investigating trajectory perception, close attention has to be paid to choosing optimum object movement speeds.

Other measures have been used in attempts to investigate infants' processing of moving object occlusion events. For instance, Baillargeon (1986) habituated infants to an event in which a truck ran down a track, disappeared behind a screen and re-emerged again. On test trials, the screen was lifted and a block was placed on or behind the track before

This research was supported by ESRC Grant R000238340, NIH Grant R01-HD40432, and NSF Grant BCS-0418103. We gratefully acknowledge the efforts of the infants and parents who participated in the studies, and extend our appreciation to Les Cohen for *Habit* computer software.

Correspondence concerning this article should be addressed to J. Gavin Bremner, Psychology Department, Lancaster University, Lancaster LA1 4YF, UK. Electronic mail may be sent to j.g.bremner@lancaster.ac.uk.

 0009-3920/2005/7605-0007

the screen was lowered again. Following this, the truck ran down the track as before, emerging from behind the screen in both cases. Six- and 8-month-old infants looked longer at the event after seeing the block placed on the track, and this was interpreted as evidence that they were capable of reasoning that the re-emergence was impossible given the placement of the block. Spelke, Breinlinger, Macomber, and Jackson (1992) used a rather similar technique to investigate the same ability in even younger infants. Infants were familiarized with an event in which a ball rolled behind a screen. In test trials, an obstruction was placed behind the screen in the ball's path, and the screen was lifted to reveal the ball at rest either against the obstruction or where it had come to rest on familiarization trials, at a position beyond the obstruction. Two-and-a-half-month-old infants looked longer at the impossible event, taken as evidence that they recognized the constraints on the ball's movements posed by the obstruction. Other evidence, however, calls into question the ability of young infants to extrapolate motion paths in order to register violations of object solidity and impenetrability in occlusion events. First, Spelke, Katz, Purcell, Ehrlich, and Breinlinger (1994) reported that infants as old as 10 months were incapable of predicting the final resting position of an object on the basis of its trajectory while in sight. Second, children as old as 2.5 years search at chance levels for objects whose location can be predicted from a previously viewed trajectory and knowledge of path obstruction (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Hood, Carey, & Prasada, 2000). Thus the ability of young infants to reason about paths of motion and object solidity is far from clear.

Other work has investigated infants' ability to infer the number of objects involved in occlusion events. For instance, Spelke, Kestenbaum, Simons, and Wein (1995) familiarized 4-month-old infants with one of two events, both of which involved object movements in relation to two screens. In one event, the object moved behind one screen, emerged, moved behind the second screen, and subsequently emerged. The other event was the same, except that the middle part of the object's trajectory (between the two screens) was missing. Test events took place with the screens removed and involved one or two objects. Infants familiarized with the continuous trajectory event looked longer at the two-object test event, whereas those familiarized with the discontinuous test event looked longer at the single-object test event. The authors took this as evidence that young infants use continuity of motion as indicating a single object and discontinuity as indicating two objects. However, in a single screen task, they presented events in which timing of object disappearance and emergence was in keeping with a constant trajectory, or violated constant trajectory by emerging too soon or too late. Infants showed no evidence of using constant vs. inconstant trajectory information to infer the number of objects involved in the event. Thus, Spelke et al. (1995) concluded that young infants use continuity of motion but not smoothness of motion as an index of the number of objects involved in an event, and fail to use trajectory information such as smoothness or direction of motion to make judgments about end states of event sequences. Recent work qualifies this conclusion, however. Wilcox and Schweinle (2003) have shown that, under certain circumstances, 3.5-month-old infants do respond to violation of smoothness of motion, although it seems likely that this only occurs when the violation takes the extreme form of instantaneous re-emergence from behind the occluder (Putthoff & Wilcox, 1997).

Investigating similar abilities in 10- and 12-month-olds, Xu and Carey (1996) replicated the finding regarding continuity of motion, but found that 10-month-olds apparently did not use information about object features, such as shape and color, to infer the number of objects involved in an event. Their task involved successive appearances and disappearances of different objects at opposite sides of a single screen. After this familiarization, infants showed no signs of expecting two objects when the screen was removed. However, Wilcox and Baillargeon (1998) obtained a more positive picture regarding use of featural information to individuate objects. In an ingeniously simple task, they presented infants with a sequence in which one object disappeared behind a screen and another (i.e., a different shaped object) emerged. This sequence either involved a wide screen that could hide two objects at once, or a narrow screen that would only hide one object. Infants looked longer at the narrow screen event, and Wilcox and Baillargeon take this as evidence that infants are aware that two objects are involved and that the narrow screen cannot hide both objects. To check that the looking preference was not to do with the narrow screen per se, they repeated the study with smaller objects such that both would fit behind the narrow screen. Under these circumstances, there was no increased looking at the narrow screen event, an outcome that strengthens their claim that longer looking in the first study was because of detection that the event sequence was impossible. Wilcox and Baillargeon argue that the reason others

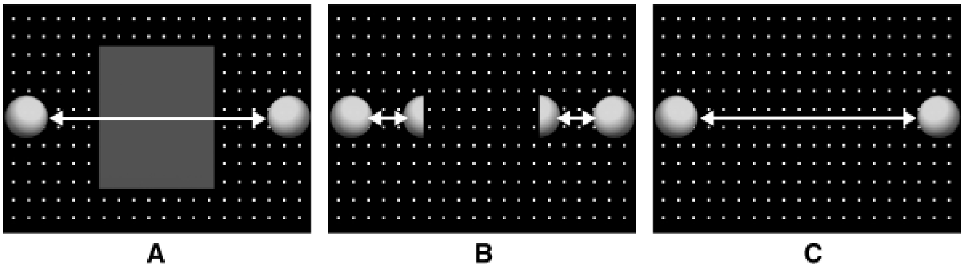

Figure 1. Schematic depiction of events shown to infants in the present experiments to gauge perception of trajectory continuity. (a) Habituation event. A ball moves behind an occluding screen and re-emerges, and then returns on a repetitive cyclic trajectory. (b) Discontinuous trajectory test event. The ball moves to the place occupied previously by the occluder and goes out of sight in the same manner. (c) Continuous trajectory test event. The ball moves back and forth as before but remains visible during the entire trajectory.

have obtained negative results regarding use of featural cues to individuate objects lies in the higher processing demands of the tasks they have used. Xu and Carey used an *event mapping* task in which infants have to judge the possibility of an end state on the basis of prior information, whereas in the *event monitoring* task used by Wilcox and Baillargeon, infants can judge the initial event itself as possible or impossible.

Although plausible accounts have been developed to explain the varied pattern of positive and negative results in the literature based on moving object occlusion events, there is reason to harbor doubts regarding what we can currently draw from this literature. In addition to the Wilcox and Baillargeon (1998) argument regarding the loads posed by event mapping tasks, the finding that object speed and occlusion time affect infants' tracking of moving objects (Mareschal et al., 1997; Muller & Aslin, 1978) should lead us to be cautious in our interpretation of the more recent work, in which object movement rates and occluder widths have varied widely between and within studies. In particular, screen width is a confounding variable in the tasks used by Spelke et al. (1995) to measure infants' use of continuity of movement and smoothness of movement. The continuity task involves two narrow screens (and hence short times and distances out of sight before re-emergence would be predicted) whereas the smoothness of movement task involves one wide screen (and hence a long distance and time over which a perceptual gap must be filled in). Additionally, longer looking at the narrow screen event in the Wilcox and Baillargeon study might arise simply through recognition of object change when the spatiotemporal gap between seeing the two is short. And although Wilcox and Baillargeon tackle a low level interpretation based on screen width by showing that the effect is lost when smaller objects are used, the fact remains that through use of smaller objects, the occlusion time in this task is longer than in the original narrow screen task.

The results of recent work confirm the importance of time/distance out of sight in moving object occlusion events. Johnson, Bremner, et al. (2003) habituated 2-, 4-, and 6-month-olds to a computer-generated event in which an object moved back and forth, passing behind an occluder for the middle section of its path, and then presented test trials with the occluder removed, which either involved the object moving on a continuous trajectory or consisted of the parts of the object's trajectory that had been visible during habituation (see Figure 1). When the occluder was 17.7 cm (10.1° visual angle), 4-month-olds looked longer at the complete test display, whereas 6-month-olds looked longer at the discontinuous test display. In other words, 4-month-olds appeared to perceive the habituation event as involving a discontinuous trajectory (thus treating the continuous test display as novel), whereas 6-month-olds appeared to perceive a continuous trajectory in the habituation event. However, when the occluder was only 7.0 cm (4.0°) wide, 4-month-olds (but not 2-month-olds) appeared to perceive the habituation event as a continuous trajectory. The occluder width effect with 4-month-olds was further examined by replicating the wide occluder finding and adding tasks using intermediate occluder widths. The outcome was an orderly relationship between occluder width and direction of preference on test trials.

This study confirms the importance of low-level perceptual factors such as time or distance out of sight in infants' perception of moving object occlusion events. Its results are in keeping with a developmental account in which there is a progressive increase in the ability to fill in gaps in perception, and there is a clear parallel here with the work on object unity, which shows that 2-month-olds only perceive object unity if the occluder is narrow, whereas 4-month-olds fill in wider perceptual gaps

(Johnson, 2004). Knowledge of object permanence may develop out of these relatively humble perceptual underpinnings, which in themselves undergo considerable development during the first 6 months.

What remains unclear is whether time out of sight or distance out of sight is the most important variable influencing perception of continuity, or whether they interact. Manipulating occluder width with object speed held constant changes both time and distance out of sight, and to better understand the processes underlying performance it is important to know whether one or both of these variables are important determinants of what the infant perceives in these events. Everyday dynamic events are ruled by strict relationships between object speed, object size, and occluder size, and it is important to understand the developmental origins of understanding these relationships. Specifically, it is of interest to know whether in their perception of these events young infants give equal weight to distance and time out of sight or give priority to one over the other.

There are various ways in which we can disambiguate these variables. For instance, we could increase the size of the ball so as to achieve a short time out of sight with a wide occluder. Alternatively, we could present different object speeds to manipulate time out of sight independent of occluder width, a complementary strategy relative to that used by Johnson, Bremner et al. (2003), who held target speed constant while varying occluder size, or we could speed up or slow down the object while it is occluded to achieve the same ends. The range of conditions that could be generated to investigate this question is extensive. However, it must be recognized that, because of the nature of the problem, it is not possible to manipulate time or distance out of sight while holding the other constant without changing another, potentially influential variable, such as ball size, ball speed, etc. Thus no single method of tackling the issue is sufficient in itself. Instead, we have to reach conclusions on the basis of results emerging from a number of different manipulations, and our strategy in this paper is to present a selection of key manipulations that we believe will best assess the relative contribution of time and distance out of sight to perception of trajectory continuity at 4 months.

Experiment 1

Johnson, Bremner et al. (2003) reported that when the speed of a small target (a 6.7 cm ball, subtending 3.8° visual angle) was held constant at 18.2 cm/s (10.4°/s), occluder width played a central role in perception of trajectory continuity. When the occluder was relatively wide (17.7 cm, 10.1°), and with a time out of sight of 667 ms, the trajectory was perceived as consisting of two separate segments (i.e., infants looked longer at a posthabituation display consisting of a continuous trajectory; see Figure 1). In contrast, when the occluder was relatively narrow (either 12.1 or 7.0 cm, 6.9° or 4.0°, and with times out of sight of 400 and 67 ms, respectively), the trajectory was perceived as continuous (i.e., infants looked longer at the discontinuous posthabituation stimulus). After viewing a display with an occluder of intermediate width (14.8 cm, 8.5°), infants preferred neither test display, as if they could not determine whether or not the visible portions of the trajectory were linked.

It is unclear from these results whether the distance or the time out of sight was a more important determinant of continuity perception, because they covaried. Our first step toward teasing apart these variables involved a simple means of altering time out of sight while holding occluder width constant. We increased the ball size to the extent that, even though it traveled at the same speed as in previous work, it was out of sight behind the 17.7 cm occluder for precisely the same time as the ball had been out of sight behind the 7 cm occluder. We reasoned that if distance out of sight is the crucial variable, we would expect to replicate the result reported by Johnson, Bremner et al. (2003) with an occluder of the same width: a test preference for continuous trajectory, indicating perception of a discontinuous trajectory during the habituation trials. However, if time out of sight is a more important variable, we would expect to replicate the result Johnson, Bremner et al. (2003) obtained with a 7 cm occluder, that is, a test preference for continuous trajectory, or at least to obtain a pattern of results indicative of an indeterminate percept (i.e., no posthabituation preference for either test stimulus).

Method

Participants. Twenty 4-month-old infants (*M* age 130.0 days, *SD* = 6.3, 11 girls and 9 boys) took part in this study. A further 2 infants did not complete the study because of fussiness. Infants in all five experiments in this report were recruited by visits to parents in the hospital shortly after the birth of the infants and follow-up phone calls. The resulting sample was predominantly Caucasian and middle class. All infants were full-term and had no known developmental difficulties.

Apparatus and stimuli. A Macintosh computer and a 76 cm color monitor were used to present stimuli and collect looking time data. An observer viewed the infant on a second monitor, and infants were recorded onto videotape for later independent coding of looking times by a second observer. Both observers were unaware of the hypothesis under investigation. The computer presented displays, recorded looking time judgments, calculated the habituation criterion for each infant, and changed displays after the criterion was met. The observer's judgments were input with a keypress on the computer keyboard.

The habituation display consisted of a stationary 21.5 (vertical) $\times$ 17.7 (horizontal) cm (12.3° $\times$ 10.1°) blue box and a 17.4 cm (9.9°) green ball undergoing continuous lateral translation back and forth at a rate of 18.2 cm/s (10.4°/s), the center of its trajectory occluded by the box (see Figure 2). The ball was visible on either side of the box for 300 ms, and was completely occluded for 67 ms. The transition from full visibility to full occlusion or the reverse took 1067 ms. The animation was run as a continuous loop for the duration of the trial. In test displays, the box was removed and the ball translated back and forth as in the habituation display. In the continuous trajectory test display, the ball was always visible. In the discontinuous trajectory display, the ball went out of and back into view just as in the habituation stimulus, but without a visible (i.e., color- or luminance-defined) occluding edge. Objects were presented against a black background with a 12 $\times$ 20 grid of white dots measuring 48.8 $\times$ 33.0 cm (27.4° $\times$ 18.7°) serving as texture elements.

Design and procedure. Infants were assigned randomly to either an experimental or a control condition. Infants in the experimental condition were first habituated to the ball-and-box stimulus, and then were presented with the 2 test displays in alternation, 3 times each, for a total of 6 test trials. Infants in the control condition were shown only the 6 test trials, with no prior habituation, to assess any possible intrinsic preference. On test trials, half the infants in each condition were presented with the continuous trajectory first, and the other half viewed the discontinuous trajectory first.

Each infant was seated 100 cm from the display and tested individually in a darkened room. For infants in the experimental condition, the ball-and-box display was presented until looking time declined across four consecutive trials, from the second trial on, adding up to less than half the total looking time during the first four trials. Timing of each trial began when the infant fixated the screen after display onset. The observer pressed a key as long as the infant fixated the screen, and released it when the infant looked away. A trial was terminated when the observer released the key for 2 or 60 s had elapsed. Between trials, a beeping target was shown to attract attention back to the screen. For the control, testing conditions were identical except that the infants were not habituated before viewing the test displays. The second observer coded looking times from the videotape for purposes of assessing reliability of looking time judgments. Interobserver correlations were high across the five experiments in this report (M Pearson $r = .99$).

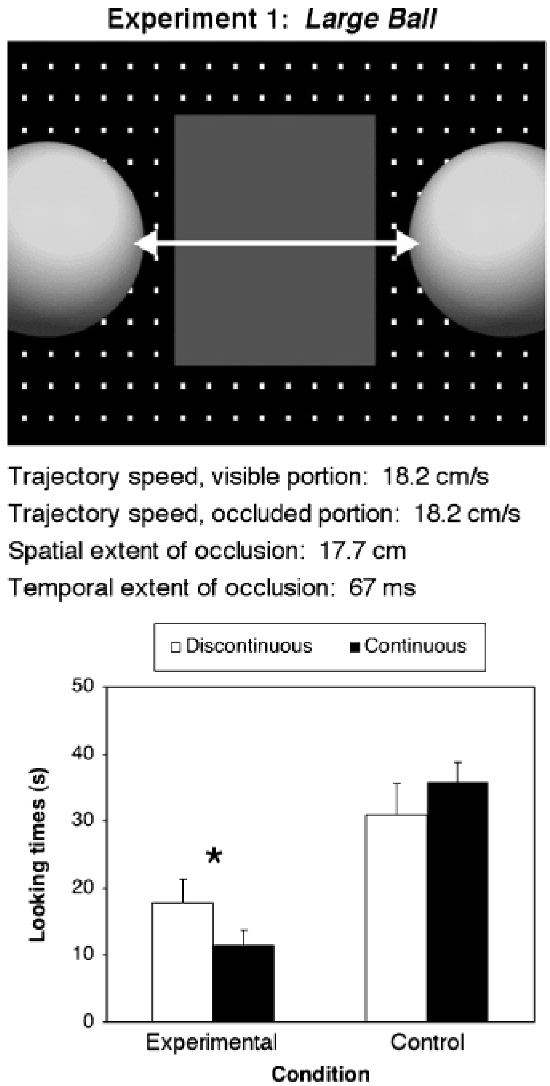

Figure 2. Habituation event shown to the Large Ball group in Experiment 1, spatiotemporal parameters, and looking time data.

Results

Looking time data in many cells were positively skewed, violating assumptions of homogeneity of variance required by ANOVA; therefore, scores were log-transformed before analysis in all the experiments in this report (data in the figures are based on raw scores). Preliminary analyses including sex and trial block revealed no reliable main effects or interactions that had a bearing on the hypotheses under investigation (i.e., no differences in performance as a function of sex or of trial); therefore, data were collapsed across these variables in all experiments.

Figure 2 shows looking times toward the test displays. Infants in the experimental condition looked longer at the discontinuous trajectory, but infants in the control condition exhibited no reliable preference. A 2 (condition: experimental vs. control) $\times$ 2 (order: discontinuous vs. continuous test display presented first) $\times$ 2 (display: discontinuous vs. continuous test display) mixed ANOVA yielded a significant main effect of condition, $F(1, 16) = 22.66$, $p < .001$. This was because of longer looking overall by infants in the control condition, a result to be expected because that group had received no prior habituation to a movement event. There was also a significant main effect of order, $F(1, 16) = 7.95$, $p < .05$, the result of longer looking overall by infants who viewed the discontinuous display first. These effects were qualified by two reliable interactions: an interaction between condition and display, $F(1, 16) = 11.42$, $p < .01$, and a condition $\times$ order $\times$ display interaction, $F(1, 16) = 4.52$, $p < .05$. Simple effects tests revealed a significant preference for the discontinuous trajectory by infants in the experimental condition, $F(1, 16) = 10.91$, $p < .01$, but no overall reliable preference in the control condition, $F(1, 16) = 2.18$, *ns*. The three-way interaction was because of a preference by infants in the control group for the type of display (discontinuous vs. continuous) presented first, probably the result of habituation during test trials.

Discussion

Reducing time out of sight by increasing ball size had a dramatic effect on infants' responses. The distance separating the two visible components of the object's trajectory was the same as in Experiment 1 of Johnson, Bremner et al. (2003), in which 4-month-olds showed a clear preference for the continuous test display, but infants in the present study showed a clear preference for the *discontinuous* test display. This outcome is comparable with that obtained by Johnson, Bremner et al. (2003) when they used a very narrow occluder (7.0 cm, 4.0°) that yielded the same time out of sight as in the present study, and suggests that, on its own, time out of sight is a major determinant of how infants perceive the trajectory.

A natural follow-up might have been to present a narrow occluder condition, with ball size reduced so as to achieve a time out of sight comparable with that for the 17.7 cm occluder display used in Experiment 1 of Johnson, Bremner et al. (2003), the prediction being that infants would perceive this trajectory as discontinuous despite the short distance out of sight. However, it is just possible that both the positive result obtained with the large ball display and a negative result in a small ball condition could be because of increasing and decreasing ball salience, respectively. Thus, we chose to build the picture further by teasing apart time and distance out of sight by other means.

Experiment 2

In this experiment, we manipulated ball speed in order to change time out of sight while holding occluder width constant. We chose to present an event sequence with the occluder width that led to indeterminate percepts in the Johnson, Bremner et al. (2003) study (14.8 cm), and ball speeds that were either faster or slower than those in the earlier report. In this case, occlusion distance is held constant but occlusion time is shorter or longer. If, as suggested by the results of Experiment 1, time out of sight is the crucial variable, we might expect that a faster ball speed would make it more likely that trajectory continuity would be perceived, and infants would look longer at a discontinuous trajectory test display; a slower ball speed would be expected to produce the opposite effect.

Method

Participants. Forty 4-month-old infants (*M* age = 125.9 days, *SD* = 9.0, 19 girls and 21 boys) took part in this study. A further 12 infants did not complete the study because of fussiness (10 infants) or failure to habituate (2 infants).

Apparatus, stimuli, design, and procedure. Unless noted otherwise, all aspects of apparatus, stimuli, experimental design, and procedure were identical to those described for Experiment 1. The habituation display consisted of a stationary 21.5 $\times$ 14.8 cm (12.3° $\times$ 8.5°) blue box and a 6.7 cm (3.8°) green ball undergoing continuous lateral translation back and forth, the center of its trajectory occluded by the box. Half the infants were assigned randomly to a *Speedball* group in which the ball in the habituation display moved at 30.3 cm/s (17.4°/s) (see Figure 3). The ball was visible in its entirety on either side of the box for 733 ms, and was completely occluded for

333 ms. The transition from full visibility to full occlusion or the reverse took 233 ms. The other infants were assigned to a *Slowball* group, viewing a ball during habituation that moved at 13.0 cm/s (7.5°/s) (see Figure 4). The ball was visible in its entirety on either side of the box for 1667 ms, and was completely occluded for 767 ms. The transition from full visibility to full occlusion or the reverse took 567 ms. In both Speedball and Slowball groups, the test displays matched the habituation display in terms of ball size and speed.

Results and Discussion

Figures 3 and 4, respectively, show looking times toward the test displays by the Speedball and Slowball groups. Infants in the Speedball group experimental condition appeared to show a preference for the continuous trajectory, perhaps indicative of a percept of the Speedball trajectory as composed of discontinuous segments during habituation. However, this preference was not statistically reliable, as revealed in the analyses. Infants in none of the other three conditions exhibited any consistent test display preference. A 2 (group: Speedball vs. Slowball) × 2 (condition) × 2 (order) × 2 (display) mixed ANOVA yielded a significant main effect of condition, $F(1, 32) = 9.34$, $p < .01$, the result of longer looking overall by infants in the control condition, and no other reliable main effects or interactions. Planned comparisons on looking times by infants in each of the 4 conditions revealed no reliable preferences, all $Fs < 1.95$, *ns*.

Reducing or increasing time out of sight by varying ball speed seemed to have no effect on 4-month-olds' perception of trajectory continuity. The null result obtained in both experimental groups is comparable with that obtained by Johnson, Bremner et al. (2003) when they used an occluder of the same width. The similarity in results suggests that, contrary to the results of Experiment 1, it is the spatial extent of occlusion rather than time out of sight that is crucial in determining whether or not infants perceive trajectory continuity, at least when this occluder width is used. However, it has been shown that infants are highly sensitive to object speed in other types of visual tracking task (Mareschal et al., 1997; Muller & Aslin, 1978), and therefore, although we were mindful of this when setting object speeds, it may be that those we selected were still suboptimal. Possibly more important, given the need to stay with a relatively limited range of object speed, our manipulations altered time out of sight to a much lesser extent than in Experiment 1 here relative to

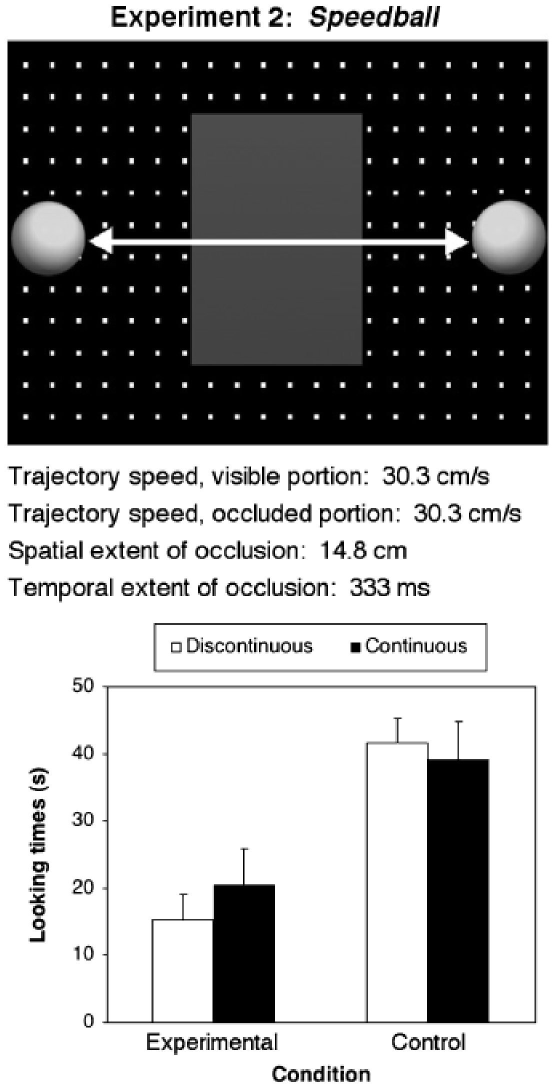

Figure 3. Habituation event shown to the Speedball group in Experiment 2, spatiotemporal parameters, and looking time data.

Experiment 1 of Johnson, Bremner et al. (2003). There are, however, other ways of effecting major manipulations of time out of sight in dynamic occlusion displays, as examined in the next three experiments.

Experiment 3

Another means of manipulating time out of sight independent of distance out of sight is to alter ball speed while it is out of sight. This manipulation has the advantage of allowing us to retain much the same visible object movement speeds as used in Experiment 1 and in previous work. On the face of it, such a manipulation might be expected to interfere with infants' perception of trajectory continuity, because it constitutes a departure from smoothness of

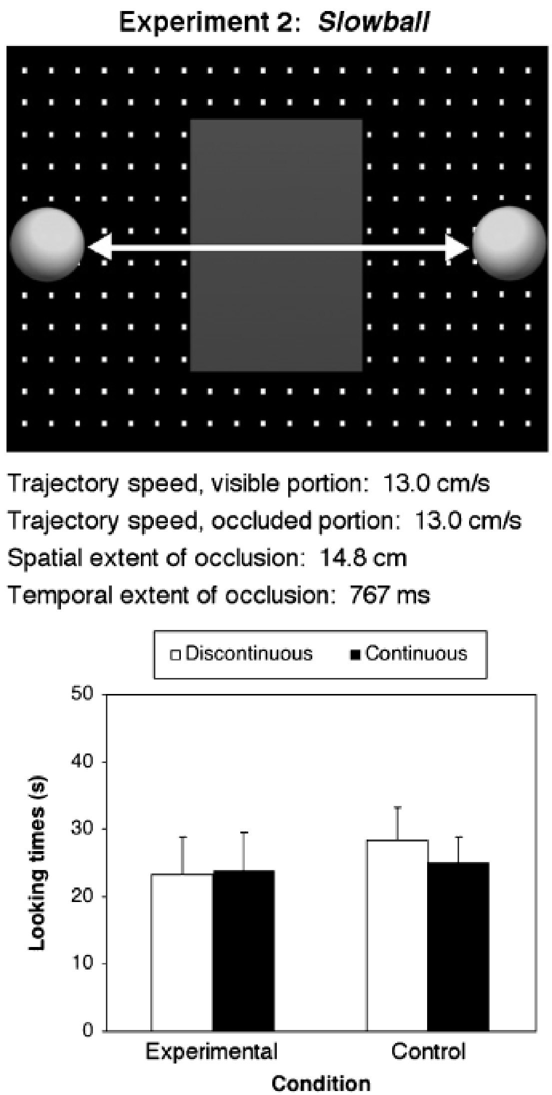

Figure 4. Habituation event shown to the Slowball group in Experiment 2, spatiotemporal parameters, and looking time data.

motion. However, Spelke et al. (1995) found no evidence that young infants used smoothness of motion to infer the number of objects involved in a moving object occlusion event, and although Wilcox and Schweinle (2003) have provided contrary evidence, it appears likely that infants are only sensitive to smoothness violations involving immediate reappearance (Putthoff & Wilcox, 1997). We thus conjecture that less extreme motion discontinuities would not impair trajectory perception. Although the necessary speeds while invisible are well outside those that lead to accurate tracking of visible objects, eye movements across the occluder involve saccades rather than tracking, and hence may be less liable to disruption. Thus, in Experiment 3, we used this method of investigating time out of sight independent of distance out of sight.

Method

Participants. Forty 4-month-old infants (*M* age 125.9 days, $SD = 9.3$, 22 girls and 18 boys) took part in this study. A further 14 infants did not complete the study because of fussiness.

Apparatus, stimuli, design, and procedure. Unless noted otherwise, all aspects of apparatus, stimuli, experimental design, and procedure were identical to those described for Experiments 1 and 2. The habituation display consisted of a stationary 21.5×14.8 cm ($12.3^\circ \times 8.5^\circ$) blue box and a 6.7 cm (3.8°) green ball undergoing continuous lateral translation back and forth (see Figure 5). Half the infants were assigned at random to an *Acceleration, Intermediate Occluder* group. They were exposed to a habituation display in which, while in view the ball moved at 15.0 cm/s (8.6°/s), and while behind the occluder it speeded up to 36.1 cm/s (20.1°/s) such that the occlusion time was 233 ms. The ball was visible on either side of the box for 1333 ms, and the transition from full visibility to full occlusion or the reverse took 467 ms. In the continuous trajectory test display, the ball accelerated at the point at which it had formerly gone out of sight behind the box, and decelerated at the point where it had emerged from behind the box in the habituation display. The rest of the infants were assigned to a *Deceleration, Intermediate Occluder* group. They were exposed to a habituation display in which, while in view, the ball moved at 19.2 cm/s (11.0°/s), and while behind the occluder it slowed down to 13.3 cm/s (7.6°/s) such that occlusion time was 700 ms. The ball was visible on either side of the box for 1133 ms, and the transition from full visibility to full occlusion or the reverse took 333 ms. In the continuous trajectory test display, the ball decelerated at the point at which it had formerly gone out of sight behind the box, and accelerated at the point where it had emerged from behind the box in the habituation display.

Results and Discussion

Figures 5 and 6, respectively, show looking times toward the test displays by Acceleration, Intermediate Occluder and Deceleration, Intermediate Occluder groups. A 2 (group) $\times$ 2 (condition) $\times$ 2 (order) $\times$ 2 (display) mixed ANOVA yielded a significant main effect of group, $F(1, 32) = 12.70$, $p < .01$, because of longer looking overall by the Deceleration group. There was also a significant main effect of

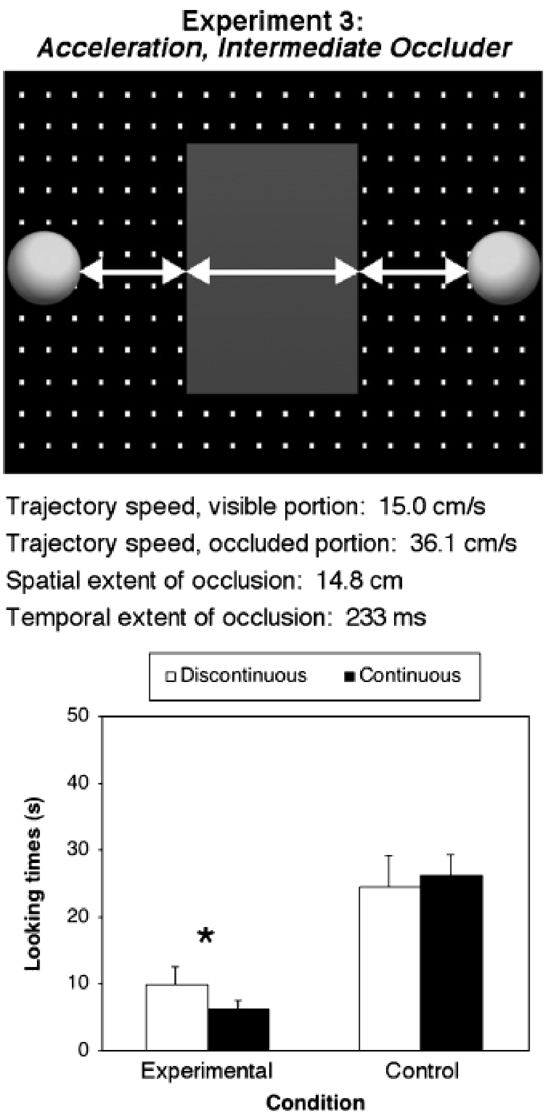

Figure 5. Habituation event shown to the Acceleration, Intermediate Occluder group in Experiment 3, spatiotemporal parameters, and looking time data.

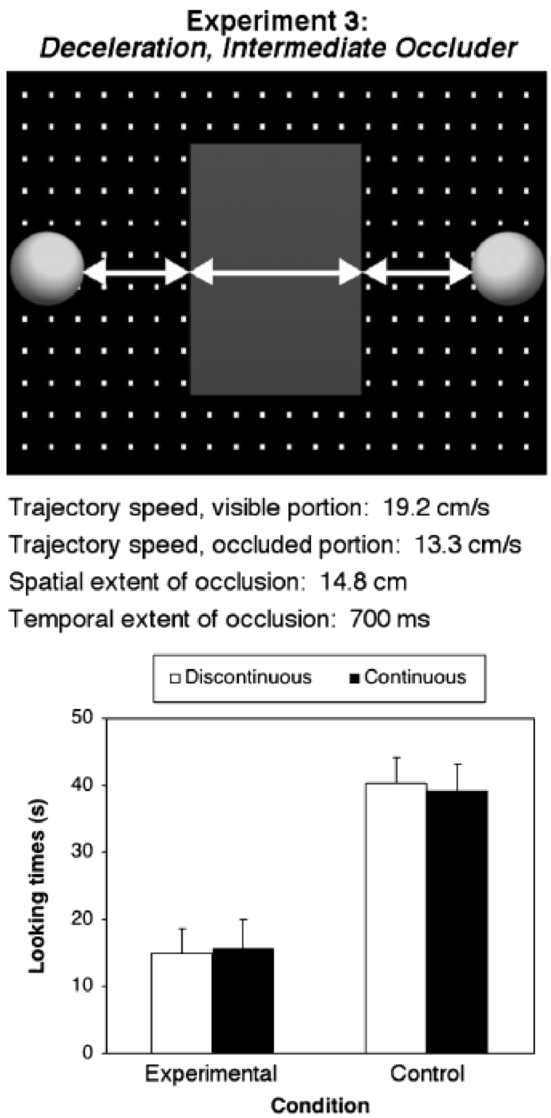

Figure 6. Habituation event shown to the Deceleration, Intermediate Occluder group in Experiment 3, spatiotemporal parameters, and looking time data.

condition, $F(1, 32) = 75.15$, $p < .001$, because of longer looking overall by infants in the control conditions. There was also a significant main effect of order, $F(1, 32) = 4.16$, $p < .05$, because of infants looking longer overall on test trials when the discontinuous display was presented first. These were qualified by a reliable three-way interaction between group, condition, and order, $F(1, 32) = 4.35$, $p < .05$. Further investigation of this interaction indicates that although the condition effect is general to both groups ($p < .001$ in both cases), the three-way interaction and the main effects of group and order can be explained by a significant interaction between condition and order in the Deceleration group, $F(1, 16) = 6.2$, $p < .05$, but not in the Acceleration Group, $F(1, 16) = .03$, *ns*, resulting from a tendency of infants in the Deceleration group experimental condition to look less overall if they were first presented with the continuous trajectory test display. The reasons for this effect are unclear, but it does not appear to be related to a test display preference that stems from perception of the habituation trajectory as either discontinuous or continuous.

In contrast, two further significant effects are highly relevant to the issue of perception of trajectory continuity. There was a significant interaction between condition and display, $F(1, 32) = 5.7$, $p < .05$, qualified by a significant three-way interaction between group, condition, and display, $F(1, 32) = 5.8$, $p < .05$. Furthermore, investigation of the 3-way interaction indicated that in the Deceleration group, the interaction between condition and display was not significant, $F(1, 16) = .0001$, *ns*, whereas in the Acceleration group, this interaction was significant, $F(1, 16) = 18.19$, $p < .01$. Infants in the Acceleration group experimental condition looked reliably longer at the discontinuous test display, $F(1, 8) = 13.24$, $p < .01$, whereas infants in the control group looked (non-significantly) longer at the continuous test display, $F(1, 8) = 5.24$, *ns*.

Speeding the ball behind the intermediate width (14.8 cm) box had a very clear effect: Infants in the Acceleration group showed a clear preference for the discontinuous test display and hence most likely perceived the habituation trajectory as continuous. In contrast, slowing the ball behind the intermediate occluder had no discernible effect on infants' responses: The same null result was obtained as in previous experiments incorporating the 14.8 cm occluder width (Experiment 2 of the present report, and Experiment 3 of Johnson, Bremner et al., 2003).

Experiment 4

In Experiment 3, we used an occluder width that yielded a null result in Johnson, Bremner et al. (2003) and demonstrated that speeding up the ball while out of sight led to a positive result. On the other hand, slowing the ball down did not lead to a negative result. Our tentative conclusion is thus that both time and distance out of sight are relevant variables in determining infants' response. If time out of sight is made short and distance out of sight is intermediate at 233 ms (relative to the comparable parameters in the conditions yielding negative and positive results in Johnson, Bremner et al., 2003), we obtain a positive result. But when time out of sight is long (700 ms), we do not move infants toward perception of discontinuity: The null result remains, perhaps because infants are responding on the basis of screen width. It is as if they make the best of what is there, basing their result on the "more favorable" intermediate occluder width. However, it seemed important to confirm this conclusion. We attempted to replicate the effect obtained in Experiment 3 in further conditions that pitted more extreme values of time and distance out of sight against each other. Thus, in Experiments 4 and 5, respectively, we tested the effects of accelerating an object while it was behind a wide screen and decelerating an object while it was behind a narrow screen. In Experiment 4, we used the 17.7 cm occluder width that yielded a negative result in Johnson, Bremner et al. (2003) but here accelerated the object so that it was out of sight for a short time.

Method

Participants. Twenty 4-month-old infants (*M* age 127.0 days, $SD = 8.0$, 10 girls and 10 boys) took part in this study. One further infant did not complete the study because of fussiness.

Apparatus, stimuli, design, and procedure. Unless noted otherwise, all aspects of apparatus, stimuli, experimental design, and procedure were identical to those described for Experiments 1–3. The habituation display consisted of a stationary 21.5×17.7 cm ($12.3^\circ \times 10.1^\circ$) blue box and a 6.7 cm (3.8°) green ball undergoing continuous lateral translation back and forth (see Figure 5). While in view, the ball moved at 14.1 cm/s (8.0°/s), and while behind the occluder it sped up to 63.5 cm/s (36.2°/s) such that occlusion time was 200 ms. The ball was visible on either side of the box for 1200 ms, and the transition from full visibility to full occlusion or the reverse took 600 ms. In the continuous trajectory test display, the ball accelerated over the lateral extent formerly occupied by the occluder, and decelerated at the point where it had emerged from behind the box in the habituation display.

Results and Discussion

Figure 7 shows looking times for the test displays by the *Acceleration, Wide Occluder* group. As in Experiment 2, infants in the experimental condition looked longer at the discontinuous trajectory, but infants in the control condition exhibited no reliable preference. A 2 (condition) × 2 (order) × 2 (display) mixed ANOVA yielded a significant main effect of condition, $F(1, 16) = 10.32$, $p < .01$, the result of longer looking overall by infants in the control condition, a significant main effect of order, $F(1, 16) = 5.23$, $p < .05$, the result of longer looking overall by infants who viewed the discontinuous display first, and a significant main effect of display, $F(1, 16) = 7.69$, $p < .05$, the result of longer looking overall at the discontinuous trajectory. These effects were qualified by three reliable interactions: an interaction between condition and display, $F(1, 16) = 18.09$, $p < .001$, an order × display interaction, $F(1, 16) = 6.29$, $p < .05$, and a condition × order × display interaction, $F(1, 16) = 4.52$, $p < .05$. Simple effects tests revealed a significant preference for the discontinuous trajectory by infants in the experimental condition, $F(1, 16) = 24.68$, $p < .001$, but no overall reliable preference in the control condition, $F(1, 16) = 1.09$, *ns*. Similar to Ex-

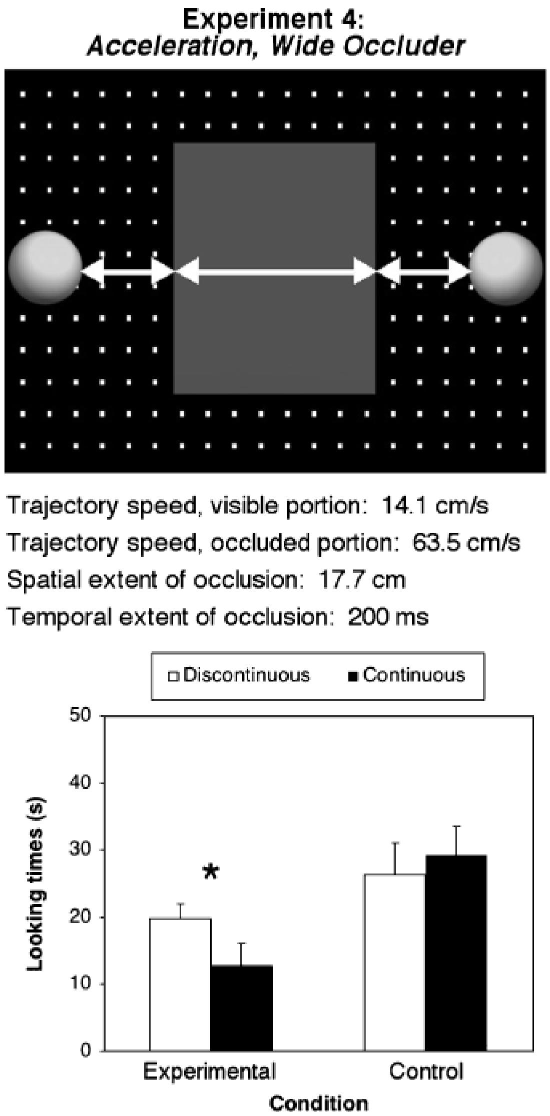

Figure 7. Habituation event shown to the Acceleration, Wide Occluder group in Experiment 4, spatiotemporal parameters, and looking time data.

periment 1, the order × display and three-way interactions were because of a preference by infants in the control group for the test display presented first.

Speeding up the ball while behind the occluder again proved an effective way of manipulating time out of sight independent of distance out of sight. Infants in the experimental condition showed clear evidence of perceiving trajectory continuity, revealing a preference for the discontinuous test display, the opposite of the result obtained by Johnson, Bremner et al. (2003) using the same occluder width and a constant object speed (and a longer occlusion duration of 667 ms). Alongside the findings of Experiments 1 and 3, the results of the present study suggest that young infants' ability to perceive trajectory continuity is facilitated by reducing temporal demands on keeping track of an object as it is out of sight. Violating smoothness of motion did not seem to have an adverse impact on the effect.

Experiment 5

If time out of sight were the only important variable, it should be possible to take a narrow occluder condition in which 4-month-olds are known to perceive trajectory continuity and abolish or reverse the effect by increasing time out of sight. Alternatively, if either a short time *or* a short distance out of sight is sufficient to support trajectory continuity, such a manipulation might not be effective. Thus, in Experiment 4, we presented infants with a "deceleration" (i.e., late emergence) version of the 7.0 cm (4.0°) occluder task (Johnson, Bremner et al., 2003; Experiment 2) in which the ball moved at approximately the original speed while in sight, but slowed down while behind the occluder so as to be out of sight as long as it was in the case of the original 17.7 cm (10.1°) occluder task (Johnson, Bremner et al., 2003, Experiment 1).

Method

Participants. Twenty 4-month-old infants (*M* age 128.8 days, *SD* = 7.1, 7 girls and 13 boys) took part in this study. One further infant did not complete the study because of fussiness.

Apparatus, stimuli, design, and procedure. Unless noted otherwise, all aspects of apparatus, stimuli, experimental design, and procedure were identical to those described for Experiments 1–4. The habituation display consisted of a stationary 21.5 × 7.0 cm (12.3° × 4.0°) blue box and a 6.7 cm (3.8°) green ball undergoing continuous lateral translation back and forth (see Figure 6). While in view, the ball moved at 24.6 cm/s (14.1°/s), and while behind the occluder it slowed down to .43 cm/s (.23°/s) such that occlusion time was 700 ms. The ball was visible on either side of the box for 1267 ms, and the transition from full visibility to full occlusion or the reverse took 300 ms. In the continuous trajectory test display, the ball decelerated at the point at which it had formerly disappeared behind the box, and accelerated at the point where it had emerged from behind the box in the habituation display.

Results and Discussion

Figure 8 shows looking times for the test displays by the *Deceleration, Narrow Occluder* group. As in

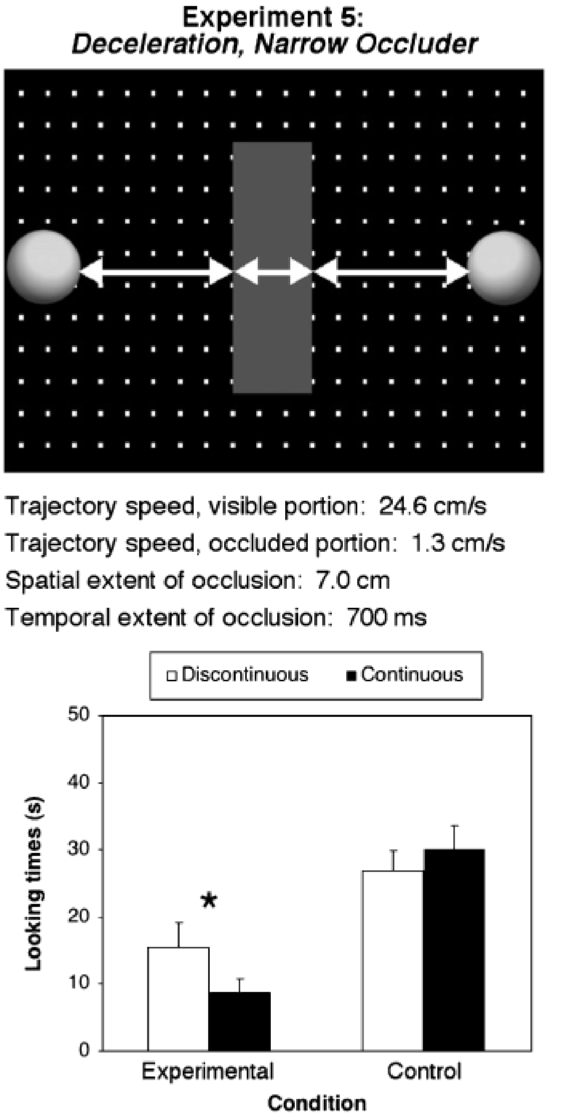

Figure 8. Habituation event shown to the Deceleration, Narrow Occluder group in Experiment 5, spatiotemporal parameters, and looking time data.

Experiments 2 and 3, infants in the experimental condition looked longer at the discontinuous trajectory, but infants in the control condition exhibited no reliable preference. A 2 (condition) × 2 (order) × 2 (display) mixed ANOVA yielded a significant main effect of condition, $F(1, 16) = 10.82$, $p < .01$, the result of longer looking overall by infants in the control condition. There was also a reliable interaction between condition and display, $F(1, 16) = 7.42$, $p < .05$, but no other reliable effects. Simple effects tests revealed a significant preference for the discontinuous trajectory by infants in the experimental condition, $F(1, 16) = 11.17$, $p < .01$, but no reliable preference in the control condition, $F(1, 16) = .26$, *ns*.

This result confirms our conclusion that distance, as well as time out of sight, is an important determinant of infants' response. Although the object in the present study was out of sight for as long as the object in the wide occluder display used by Johnson et al. (2003b), infants nevertheless perceived trajectory continuity. It appears they perceive trajectory continuity if either the temporal or the spatial gap in perception is small.

General Discussion

This series of studies has clarified the conditions under which young infants perceive continuity of an object's trajectory as it passes behind an occluder. Increasing object size so as to achieve a very short time out of sight behind a wide occluder leads to perception of trajectory continuity. However, changing object speed, under the conditions in which we tested it, appeared to have little bearing on facilitating or impairing perception of trajectory continuity. In contrast, reducing time out of sight by increasing the speed of the object while it was behind an intermediate width occluder converted the null response normally obtained with that occluder width to a positive result, and doing the same behind a wide occluder reversed the original result for that screen width, with infants showing clear perception of continuity. The opposite manipulation did not have the same effect: Infants who saw an object that slowed while occluded by an intermediate width screen still gave a null response, as if having no percept of the trajectory as continuous or discontinuous, and infants who saw an object that slowed behind a narrow occluder still perceived continuity. We believe that the various null results we obtained in this series are readily interpreted in relation to positive and negative results in this series and in previous work, but the reader might wonder whether they arose because infants were fatigued following habituation. We believe that such an interpretation is unlikely. Although looking times in the control conditions are generally a good deal higher than in the experimental conditions, longer looking by control infants is predictable because they have not been exposed to any display before the test. Also, the looking times in the experimental conditions are comparable with those in our previous paper (Johnson, Bremner et al., 2003) in which only one null result arose.

The results of Experiments 3–5 arose despite the fact that these manipulations violated constancy of trajectory speed. This outcome is in keeping with the claim by Spelke et al. (1995) that young infants do not use smoothness of motion in object identity judgments, but appears to conflict with Wilcox and Schweinle's (2003) finding that young infants are sensitive to violations of smoothness. It may be, however, that the violations involved in our manipulations were not sufficient to be noted (Putthoff & Wilcox, 1997), and it would be of interest to see whether an instant re-emergence condition would make speed discontinuity sufficiently salient to lead to perception of trajectory discontinuity in our task.

We offer two conclusions. The first is that there are clear spatial and temporal constraints on young infants' perception of object trajectories where part of the trajectory is hidden from their view. The second is that at 4 months, perception of trajectory continuity is readily facilitated, but less readily impaired. Each conclusion is considered in more detail below.

Spatiotemporal Constraints on Infants' Perception of Object Trajectories

There appear to be just two conditions under which 4-month-olds perceive the continuity of the object's movement under the conditions we examined: when the time or the distance over which the object is out of sight is short. Our finding that strict temporal and spatial constraints apply to young infants' perception of object trajectories evokes accounts of infants' responses to occlusion events that are framed in terms of short-term storage of sensory information (Haith, 1998). According to such accounts, infants' responding in tasks purportedly measuring infant knowledge of object permanence and the rules constraining object movement (e.g., Baillargeon, 1986) can be explained in terms of short-term sensory storage of information about a temporarily hidden object. The argument is that positive results on these tasks are only obtained when the period of occlusion is very short, and there is growing evidence for limits on object memory in early infancy (Ruffman, Slade, & Redman, in press). Certainly, accounts framed in terms of reified or concrete knowledge of object permanence do not explain the present results well. At minimum, such ''knowledge'' appears to be quite inflexible in young infants. The Haith account, however, seems best fitted to explaining persistence of a static object's image while it is occluded. In our task, infants never see the object on the hidden part of its trajectory, and a full account of development of object representations must explain how infants come to interpolate an image of the object during its period behind the screen. This is more than simple storage of a previously perceived event across a particular range of positions (those hidden by the occluder), because the occluded portion of the trajectory was never experienced directly. It is our proposal that young infants' visual systems interpolate a continuous trajectory, a kind of spatiotemporal ''perceptual filling-in,'' but only under short spatial or temporal occlusion periods.

Such an account has interesting parallels with evidence and arguments in the literature on visual cognition in adults using object-tracking tasks. Pylyshyn and Storm (1988) reported that adult observers can keep track of up to five multiple, independently moving targets and distinguish them from non-target distracters, also moving independently. Importantly, performance in this paradigm is not impaired when targets periodically disappear for short periods, either by the introduction of a visible occluder or an implied occluding surface with no visible contours (Scholl & Pylyshyn, 1998), or by ''blinking'' the display elements off and on, under conditions when all objects disappear momentarily (Horowitz, Birnkrant, Wolfe, Tran, & Fencsik, 2004). Successful object tracking is in large part immune to many spatiotemporal characteristics of disappearance and reappearance, such as the spatial location of a target that again comes into view after going out of sight. For example, in blinking (momentary disappearance) conditions, discrimination of targets from distracters was not improved when the targets reappeared in locations consistent with their earlier velocities (speed plus direction) compared with conditions in which they reappeared in the exact location where they were seen just before disappearance, as if they suddenly stopped moving during the delay and then abruptly began to move again (Keane & Pylyshyn, 2005). Certain violations of temporal parameters, however, do cause a performance decrement, as when objects are slowed down during occlusion (Scholl & Nevarez, 2002), although such a manipulation has less of an effect during blinking (Keane & Pylyshyn, 2005). Tracking performance is not affected by speeding up the targets during occlusion until the speed during occlusion reaches 10 times the pre-occlusion rate, causing the target to reappear almost immediately across the spatial gap (Scholl & Nevarez, 2002).

In our experiments with infants, reducing occlusion time had only positive effects on performance, and increasing it had minimal effects. It seems that infant- and adult-tracking systems are alike in that they fail to take account of constraints on smoothness of object movement, treating as the same an object seen to reappear on a path occupied by another object with a similar velocity, even if perceptual linking of the two path segments necessitates a gross violation of the way objects typically behave in the real world. Likewise, extending the time out of sight produces performance decrements for both infants and adults. There are exceptions to this latter finding, however. For infants, an extended temporal duration (700 ms) can be overcome by a narrow spatial gap (Experiment 4), and for adults, an extended temporal duration (900 ms) can be overcome if object disappearance does not involve occlusion (Keane & Pylyshyn, 2005). A tentative conclusion from this body of evidence is that development beyond infancy does not yield full accuracy in determining trajectory continuity from spatiotemporal information, suggesting that the visual system is limited in its capacity to predict object movements when not in view. Spatial proximity is exploited by both infants and adults to achieve perceptual continuity, even to the extent of discarding temporal cues.

Implications for Perceptual Development

The first 6 months after birth encompass a fundamental shift in how infants perceive occlusion events, from an initial registration only of the visible parts of a display, to perception of occlusion and implied surface and motion segments (Johnson, 2001; Johnson, Amso, & Slemmer, 2003). Four months is a pivotal age in the process of perceiving trajectory continuity: depending on display characteristics, 4-month-olds may perceive an occluded trajectory as composed of a single, continuous event (Experiments 1, 3–5 of the present report; Johnson, Bremner et al., 2003, Experiment 2), as indeterminate (Experiments 2–3 of the present report; Johnson, Bremner et al., 2003, Experiment 3), or as composed of discrete path segments (Johnson, Bremner et al., 2003, Experiments 1 and 3). Notably, this latter outcome is induced only under the most difficult conditions used to date: an extended temporal duration coupled with a wide spatial gap. When either temporal or spatial demands are eased, performance improves.

We conclude, therefore, that 4 months of age is a period in perceptual development when infants are readily influenced by our attempts to facilitate performance in dynamic occlusion tasks. Specifically, they respond on the basis of the single most "favorable" dimension (spatial or temporal) that the task offers. This may arise because they have not fully integrated spatial and temporal dimensions of dynamic events of this sort. However, it is not clear that even adults possess this skill fully, because anecdotal reports indicate they are not aware of the acceleration of the object behind the screen. Alternatively, infants are predisposed to respond on the basis of the information most supportive of veridical perception. This suggestion is confirmed by parallel attempts to induce perception of trajectory continuity with a paradigm in which anticipatory eye movements provide the measure of continuity perception (Johnson, Amso et al., 2003). Baseline comparisons of 4- and 6-month-olds who viewed a wide-occluder event revealed a striking difference in anticipation rates, with older infants producing a higher proportion of anticipations to reactive eye movements relative to younger infants. Performance of 4-month-olds (indexed by the proportion of anticipations to reactions) was brought to the same level as 6-month-olds, however, when the infants first viewed an object moving continuously on an unoccluded trajectory.

The question arises of whether training involving an object moving discontinuously on an unoccluded trajectory would lead to a reduction in anticipation in the occlusion event. On the basis of our interpretation of the findings of the present report, the prediction is that this would not occur. This prediction stems from the notion that the developmental process, in addition to being dynamic, is also directional. In the present experiments, we have provided evidence that performance of infants in the transition toward veridical occlusion perception can be propelled in a direction consistent with the overall developmental trajectory, but that it is resistant to attempts to move it in the opposite direction. Object continuity is the general rule in the physical world, and although our results suggest that young infants do not have a general knowledge of the permanence of objects, the asymmetry we have detected here may reflect a perceptual bias that has the developmental outcome of attracting infants along a particular developmental trajectory that has knowledge of permanence as its endpoint. At a very general level, there may be a parallel between this suggestion and Quinn's (2002) view that asymmetries in early perceptual categorization act as "magnet regions" through which infants acquire knowledge through perceptual learning. The general principle in both cases is that early perceptual biases determine the direction of development and the form of later perceptual and conceptual structure.

References

Baillargeon, R. (1986). Representing the existence and location of hidden objects: Object permanence in six- and eight-month-old infants. *Cognition*, *23*, 21–41.

Berthier, N. E., DeBlois, S., Poirier, C. R., Novak, M. A., & Clifton, R. K. (2000). Where's the ball? Two- and three-year-olds reason about unseen events. *Developmental Psychology*, *36*, 394 – 401.

Bower, T. G. R., Broughton, J., & Moore, M. K. (1971). Development of the object concept as manifested in changes in the tracking behavior of infants between 7 and 20 weeks of age. *Journal of Experimental Child Psychology*, *11*, 182 – 193.

Goldberg, S. (1976). Visual tracking and existence constancy in 5-month-old infants. *Journal of Experimental Child Psychology*, *22*, 478 – 491.

Haith, M. M. (1998). Who put the cog in infant cognition? Is rich interpretation too costly? *Infant Behavior & Development*, *21*, 167 – 179.

Hood, B. M., Carey, S., & Prasada, S. (2000). Do 2-year-olds predict physical events that young infants seem to know? *Child Development*, *71*, 1540 – 1554.

Horowitz, T. S., Birnkrant, R. S., Wolfe, J. M., Tran, L., & Fencsik, D. E. (2004, May). *Tracking invisible objects*. Poster presented at the Annual Vision Sciences Society Meeting, Sarasota, FL.

Johnson, S. P. (2001). Visual development in human infants: Binding features, surfaces, and objects. *Visual Cognition*, *8*, 565 – 578.

Johnson, S. P. (2004). Development of perceptual completion in infancy. *Psychological Science*, *15*, 769 – 775.

Johnson, S. P., Amso, D., & Slemmer, J. A. (2003). Development of object concepts in infancy: Evidence for early learning in an eye-tracking paradigm. *Proceedings of the National Academy of Sciences (USA)*, *100*, 10568 – 10573.

Johnson, S. P., Bremmer, J. G., Slater, A. M., Mason, U., Foster, K., & Cheshire, A. (2003). Development of object concepts in infancy: Evidence for early learning in an eye-tracking paradigm. *Proceedings of the National Academy of Sciences (USA)*, *100*, 10568 – 10573.

Keane, B. P., & Pylyshyn, Z. W. (2005). *Is trajectory extrapolation used to track multiple objects in MOT*? Revision under review.

Mareschal, D., Harris, P., & Plunkett, K. (1997). Effects of linear and angular velocity on 2-, 4-, and 6-month-olds' visual pursuit behaviors. *Infant Behavior & Development*, *20*, 435 – 448.

Meicler, M., & Gratch, G. (1980). Do 5-month-olds show object conception in Piaget's sense? *Infant Behavior and Development*, *3*, 265 – 282.

Moore, M. K., Borton, R., & Darby, B. L. (1978). Visual tracking in young infants: Evidence for object identity or object permanence? *Journal of Experimental Child Psychology*, *25*, 183 – 198.

Muller, A. A., & Aslin, R. N. (1978). Visual tracking as an index of the object concept. *Infant Behavior & Development*, *1*, 309 – 319.

Putthoff, A., & Wilcox, T. (1997, April). *Young infants' use of discontinuity of speed to reason about object identity*. Presented at the Annual Meeting of the Southwestern Psychological Association, Fort Worth, TX.

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision*, *3*, 1 – 19.

Quinn, P. C. (2002). Beyond prototypes: Asymmetries in infant categorization ands what they teach us about the mechanisms guiding early knowledge acquisition. *Advances in Child Development & Behavior*, *29*, 161 – 193.

Ruffman, T., Slade, L., & Redman, J. (in press). Young infants' expectations about hidden objects. *Cognition*.

Scholl, B. J., & Nevarez, H. G. (2002, November). *Why so slow?: The role of speed discontinuities in maintaining object persistence through occlusion*. Paper Presented at the Annual Meeting of the Psychonomic Society, Kansas City, KS.

Scholl, B. J., & Pylyshyn, Z. W. (1998). Tracking multiple items through occlusion: Clues to visual objecthood. *Cognitive Psychology*, *38*, 259 – 290.

Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*, *99*, 605 – 632.

Spelke, E. S., Katz, G., Purcell, S. E., Ehrlich, S. M., & Breinlinger, K. (1994). Early knowledge of object motion: Continuity and inertia. *Cognition*, *51*, 131 – 176.

Spelke, E. S., Kestenbaum, R., Simons, D. J., & Wein, D. (1995). Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology*, *13*, 113 – 142.

Wilcox, T., & Baillargeon, R. (1998). Object individuation in infancy: The use of featural information in reasoning about occlusion events. *Cognitive Psychology*, *37*, 97 – 155.

Wilcox, T., & Schweinle, A. (2003). Infants' use of speed information to individuate objects in occlusion events. *Infant Behavior & Development*, *26*, 253 – 282.

Xu, F., & Carey, S. (1996). Infants' metaphysics: The case of numerical identity. *Cognitive Psychology*, *30*, 111 – 153.