Journal of Experimental Psychology:
Human Perception and Performance
2001, Vol. 27, No. 4, 942–952

0096-1523/01/$5.00 DOI: 10.1037//0096-1523.27.4.942

Infant Sensitivity to Trajectory Forms

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The authors investigated whether infants are sensitive to visual event trajectory forms, and whether they are sensitive to the underlying dynamics of trajectory forms. The authors habituated 8-month-old infants to a videotaped event run either forward or reversed in time and then switched them to the same event run in the opposite direction. Infants dishabituated when switched to the event with the novel direction in time, indicating sensitivity to the form of the trajectory. Infants exhibited equivalent habituation rates and looking times for forward and reversed events, thus failing to provide evidence that infants are sensitive to the underlying dynamics. In a partial replication of this first experiment, the same pattern of results was found. Both experiments revealed infant sensitivity to the trajectory forms, but not the underlying dynamics of events. The authors discuss implications for methods used in infant event perception studies.

From the time they are born, infants encounter an immense number of different types of events. They encounter animate events including, for instance, the motions of people around them. They also experience inanimate events involving various types of rigid (e.g., bouncing balls) and nonrigid (e.g., water in the bath) motions. By adulthood, people are certainly able to discriminate and recognize these different types of events. When do people develop this ability and what is the information that they detect and use to identify events?

An obvious source of information for event identification is motion. A method for isolating the information in motion is Johansson's (1973) patch-light technique. In a patch-light display, white patches are placed on an object, such as on the joints of a walking person. The object is then filmed in the dark, so that only the patches are visible. Motion is the only source of information remaining in the display. When such displays are freeze-framed, all the structure in motion is eliminated and events become unrecognizable. Under patch-light conditions, adults are able to recognize a wide variety of events (for review, see Bingham, 1995; Bingham, Rosenblum, & Schmidt, 1995). However, the specific spatiotemporal structures that allow people to recognize events such as ocean waves or a bouncing ball remain to be discovered.

Johansson (1973) showed that relative motions among patches are an important source of information about events. For instance, in a patch-light walker the limbs are seen to swing back and forth relative to the trunk while the whole body translates forward. However, in addition, the motion of any given point is also structured in ways specific to an event. The limbs exhibit nearly harmonic motion reflecting their pendulum-like character. The motions of a walking person are determined by the dynamics, the underlying natural laws (mass and force structure) of the event. Bingham et al. (1995) suggested that differences in dynamics should determine recognizable types of events. They investigated the ability of adults to identify events representing a variety of dynamic types including rigid events, nonrigid hydrodynamic and aerodynamic events, and biodynamic or animate events. Adult observers were easily able to recognize all of these types shown in patch-light displays, and in particular, they were able to distinguish between hydro- and aerodynamic events, as well as animate and inanimate events. In the latter case, only subtle differences in trajectory forms were available as information about the animate or inanimate nature of the events, respectively. This was investigated following a suggestion by Bingham (1987) that trajectory forms are a prime source of information used by adults for event identification.

The trajectory form of an event is generated by variations in velocity, that is, both in direction and speed of movement. A trajectory form consists of the shape of both the path of motion and the variations in speed along the path (or speed profile). "Trajectory form," the characteristic shape of the speed profile (and path), should not be confused with "trajectory" itself, which can differ from other trajectories in amplitude and period. Different trajectories can have the same trajectory form. One way to study adult sensitivity to trajectory forms would be to vary the shape of a path while holding the speed profile constant (e.g., moving an object at constant speed around the perimeter of a triangle versus a square). Alternatively, one might alter the speed profile while holding the path constant. Muchisky and Bingham (1995, in press) used the latter method and showed that adults are sensitive to very slight changes in speed profiles, such as those shown in Figure 1. In this study, observers were shown computer-generated displays of a ball oscillating back and forth along a straight path. The path and period of motion were held constant, but the amplitude was varied between a standard and a "distorted" display used in a two-alternative, forced-choice task. The variation in amplitude (with period constant) meant that velocities at any given point in time or

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We thank Peter Pajakowski and Heather Sauer for their assistance in data collection and coding, as well as the parents and infants for their participation in this study. We also acknowledge our appreciation for the comments and suggestions made by Dennis Proffitt, Elizabeth Spelke, and an anonymous reviewer on an earlier version of this article.

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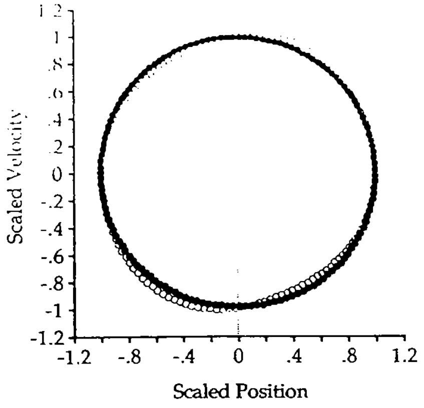

Figure 1. Velocity profile of oscillating ball event used by Muchisky and Bingham (1995). Scaled velocity is plotted against scaled position, where the black dots represent the symmetrical event, and the open dots represent the distorted/asymmetric movement. Adults were sensitive to this slight difference in position of peak velocity. From "Event Identification via Dynamically Governed Trajectory Forms," by M. Muchisky and G. P. Bingham, 1995. Poster session presented at the eighth International Conference on Perception and Action, Marseille, France. Reprinted with permission.

relative position were different in the standard and distorted displays. This isolated trajectory forms the only basis for comparison. The only difference between the displays was the shape of the velocity profile. In the standard event, the peak velocity occurred at the midpoint of the linear path, making the trajectory form symmetric, whereas in the distorted events, the peak velocity occurred at points progressively displaced to one side of the midpoint. The distortion was parametrically increased, moving the position of the peak velocity farther from the path's midpoint.[1] The form became more skewed. Adults were sensitive to this difference and used it to identify the perturbed event. Observers were similarly sensitive to other changes in the shape of velocity profiles that preserved the symmetry but varied the peakedness or kurtosis. These results were consistent with the earlier finding that adults could distinguish inanimate and animate events based only on the differences in the respective velocity profiles of simple bounce or pendular events. The experiments showed that adults are sensitive to the information in the velocity profiles of different events. Our question here is when and how this sensitivity develops.

Infant Event Perception

This question is especially relevant to infant event perception research focused on infant sensitivity to physical or dynamic constraints on motion. The earliest dynamic constraint to be investigated in infant vision was rigidity. Gibson, Owsley, and Johnston (1978) habituated 5-month-old infants to a rigid object undergoing rigid transformations including translation and rotation around various axes. During testing, the object was shown undergoing a new rigid transformation, or a new nonrigid deformation that was inconsistent with the previously learned rigidity of the object. Infants dishabituated when presented with the nonrigid transformation but not when presented with the new rigid transformation. The object was a foam disk with a visible surface texture. The foam could be squeezed from behind, thus creating the nonrigid deformation. The results of the study indicated that infants are sensitive to rigidity as a constraint on motions in an event. However, motion was not isolated as a source of information in that study, so it remained possible that infants dishabituated to the nonrigid deformation because of the presence of a static image property from the foam circle, rather than from the motion alone. However, in a later study, Spitz, Stiles, and Siegel (1993) investigated how well infants can detect the difference between individual points of light moving coherently (rigid motion) or incoherently (nonrigid) with respect to one another. They found that infants were not able to discriminate between the two types of motion until 7 months of age. In those displays, the trajectory form of each light element was held constant. Each light moved with constant velocity along a constant curved path. Only the relation between the lights (i.e., the relative motion) varied.

Infant event perception studies have explored infant sensitivity to other dynamic constraints besides rigidity, but these studies have entailed manipulations of trajectory forms rather than only relative motion. Kim and Spelke (1992), for instance, examined infants' sensitivity to the motions of objects that violated the law of gravity. Infants were shown videotaped events of a ball rolling downward (or upward) while speeding up (or slowing down). After they habituated, the infants were switched to events in which the ball moved in the opposite direction with either appropriate acceleration (i.e., either speeding up while rolling downhill or slowing down while rolling uphill) or inappropriate acceleration (slowing down while rolling downhill or speeding up while rolling uphill). The displays with the inappropriate acceleration were constructed by turning the video camera 60° so the slope was changed from downhill to uphill and vice versa. The results showed that 7-month-old infants looked longer at the event with inappropriate acceleration, a result that is consistent with adult studies showing a change in event identification based on changes in the trajectory form orientation with respect to gravity (Bingham et al., 1995). Kim and Spelke concluded that the infants were sensitive to the effects of gravity. However, this result also indicates that the infants were sensitive to the oriented trajectory forms. Spelke, Breinlinger, Macomber, and Jacobson (1992) investigated this sensitivity in 4-month-old infants and found it lacking. In their discussion of the extant results, they suggested that sensitivity to the effects of gravity as well as of inertia develops during the 1st year and remains limited and/or fragile until about 1 year of age. Spelke et al. also reported that the younger infants did seem to be sensitive to continuity and solidity constraints on motions in events.

There are, however, two issues (at least) involved in assessing developing sensitivities to dynamic constraints on events. To discriminate among events that either do or do not exhibit the effects of dynamic constraints, infants must first be sensitive to the relevant properties of motion that serve as sources of information. Logically, only after they have that sensitivity can they then develop sensitivity to natural regularities occurring in those properties. So, for instance, if an observer were only able to detect absolute motion without sensitivity to relative or common motion, then he or she could not discriminate rotation, expansion, or contraction as forms of relative motion. On the other hand, an

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[1] This was accomplished by increasing the coefficient on a nonlinear damping term in the dynamical equation used to generate the motion.

infant observer might well be able to discriminate optical expansion and contraction without being sensitive to either as being information about the approach or retreat of a rigid object or about the change in size of a nonrigid object. It is possible that infants could be sensitive to differences in forms of motion without being sensitive to the regularities represented by particular motion forms. On the other hand, if infants are to become sensitive to the regularities, they must be sensitive to forms of motion as such.

Given these considerations, our main goal was to determine whether infants are sensitive to trajectory forms. We first used a relatively simple rigid event to test this. We chose an event that was spatially, but not temporally, symmetric so only the velocity profile would change when the event was reversed in time. In the display, a patch-light ball traveled the same path whether viewed forward or reversed in time, but the way velocity varied along the path was different. To test sensitivity to this difference, we habituated 8-month-old infants to videotaped events run either forward or reversed in time, and then switched the display to run in the opposite direction, reversed and forward, respectively. Because the same spatially symmetric event was run in both directions, the only difference between the forward and reversed displays was the shape of the velocity profiles. (The moving object was the same. The path of motion was the same. The duration of the event was the same. The images in the display were the same as were the relative sequence and the frame rate. Only the absolute order in time was different and thus, the velocity profile.) Thus, if infants looked longer at one display after being habituated to the other, their sensitivity to trajectory forms would be apparent, whereas lack of dishabituation would indicate their inability to detect differences in trajectory forms. We hypothesized that 8-month-old infants would be sensitive to the differences in trajectory forms of a simple rigid event. This event (when run forward) consisted of a simple rapid increase and then a somewhat more gradual but still rapid decrease in velocity, reflecting the dissipation of energy over time.

To investigate the generality of the result, we also tested whether infants would be sensitive to the trajectory forms of a more complex nonrigid event. The same technique was used. A video recording of a splash was shown either forward or reversed in time. Small pieces of white styrofoam floated on the surface of the water and were recorded as the patches in a patch-light display. Unlike the rigid event, the nonrigid event involved repeated increases and decreases in velocity occurring at a variety of locations and directions of motion. The dissipation of motion occurred more gradually over successive oscillations in the event as the mean and peak velocity of oscillation decreased. Motion did not cease by the end of the display. Given the complexity of the event and the subtlety of the dissipation of motion over time, the discrepancy between the forward and reversed displays might be difficult for the infants to resolve. Performance with this display would provide an indication of the extent to which sensitivity to trajectory forms can be expected to generalize.

Our final goal was to investigate whether infants are sensitive to the dynamical significance of the differences in trajectory forms of forward and reversed events. If they are sensitive, they should easily recognize the differences between the forward events that are possible and the reversed events that are impossible. In classic habituation studies, an infant's looking time to an impossible event is recorded after the infant has been repeatedly exposed to a related possible event. The assumption is that during habituation the infant becomes familiar with the parameters of the display and once familiar becomes bored and stops looking at it. It is also assumed that the infant is already familiar with the specifically possible character of the event. Infants are then shown both a new possible event and an impossible event, and the looking times are compared. This controls for the novelty of everything in the impossible display other than a change specific to the impossible character of the event. If an infant is sensitive and reacting to the impossibility, then he or she should look longer at the impossible display and thus, exhibit dishabituation, which would be interpreted as evidence for the infant's sensitivity to the possible versus impossible dimension. Habituation studies have shown that infants do look longer at impossible events that differ in some nominally relevant respect to a possible event (e.g., a box released by a hand, unsupported in the air, seemingly floating, versus a box placed on top of another box; Baillargeon, 1995).

Our method controlled for the content of our display beyond that specific to the impossibility of the event by using exactly the same display during habituation and test, including the same sequential set of images but with the velocity form changed by running the sequence in reverse. This control is more exact than that used in previous studies because it ensures that only the dimension of interest changes. We investigated whether infants would habituate to the forward and reversed events at different rates, and whether they would exhibit longer looking times when dishabituating to one as opposed to the other event. Both measures (i.e., relative rate of habituation and amount of dishabituation) have been used in previous studies (e.g., Benasich & Tallal, 1996; Pecheux & Lecuyer, 1989; Premack & Premack, 1997; Schiff, Benasich, & Bornstein, 1989).

Presumably, 8-month-old infants will have had extensive experience with events running forward in time, but not with events running backward in time (given that it is impossible in the real world, and exposure to television at that age is usually minimal). When shown an event run backward in time, infants might be expected to look longer. The reversed events looked quite peculiar to adult observers. However, Spelke (1985) and Spelke et al. (1992) argued that longer looking times cannot be taken as evidence of sensitivity to the impossibility of events. They argued that relatively longer looking times might be equally well predicted for possible events that are expected by the infant observers.

Nevertheless, differences in looking times or rates of habituation without regard to the direction of the difference must be treated as evidence of sensitivity to a difference in the events if the habituation paradigm is to be regarded as providing useful evidence. In the paradigm, the evidence for sensitivity is a significant difference in looking time. Assuming appropriate controls for the contents of the displays, the only difference in the displays being compared would be the variable under study. A significant difference in response is one that is reliable in the population. If infants reliably respond to the variable under study, then they must be sensitive to it. Spelke (1985) and Spelke et al. (1992) argued that one cannot predict which event might yield the longer looking times or greater resistance to habituation. Nevertheless, a reliable difference in these measures can only be attributed to the infants' experience or state before entering the experiment. The looking time result representing dishabituation reflects boredom with experience during the experiment and interest provoked by noticed change during the experiment. Differences in habituation rates must reflect experience or state preceding the experiment. It is thus reasonable to treat such differences as evidence concerning sensitivity to the lawful character of the events. Of course, as also noted by Spelke et al., the absence of a difference in looking time or in the rate of habituation cannot be treated as conclusive evidence that infants are not sensitive to differences in the events. Such a result merely fails to provide positive evidence that they are sensitive.

Our methods allowed us to test separately for infant sensitivity to trajectory forms and to dynamics. We thought that the infants might exhibit sensitivity to the differences in trajectory forms by dishabituating to forward and reversed displays while not exhibiting sensitivity to the dynamics (i.e., impossibility of reversed events). We expected this outcome because sensitivity to the relevant kinematic properties of events, such as trajectory forms, would be a necessary precursor to the development of a sensitivity to dynamically determined regularities or invariance of trajectory forms.

The events we used in this study were a rolling ball, a ball splashing into a bucket of water, and a face on a pole that swung out from behind a barrier. We tested 8-month-old infants for the following reasons. First, previous experiments have suggested that sensitivity to trajectory forms emerges sometime around 7 months. As already mentioned, Kim and Spelke (1992) found 7-month-old infants to be sensitive to orientation-specific changes in trajectory forms. Many infant studies have reported finding strong and stable sensitivity to dynamic constraints using the habituation method around the age of 8 months (unlike studies using younger infants where mixed results are often found; for review, see Baillargeon, 1995). We chose 8-month-olds rather than younger infants because they were likely to be sensitive, and we chose 8-month-olds rather than older infants to keep their exposure to television, and thus exposure to time-reversed events, to a minimum. A final reason for testing 8-month-olds was that if we found sensitivity to trajectory forms at that age, we could directly evaluate the possible implications for other habituation studies on event perception performed with infants of that age.

Experiment 1

Method

Participants. Sixty 8-month-old infants participated in the study. Names were obtained from birth announcements in the local newspaper. The data of 24 infants were retained (40%), and the data of 36 were discarded due to extreme fussiness or crying, parental influence, or experimenter error. We attributed the high rate of fussiness first to the use of a video display (as opposed to a live display), which was devoid of sound as well as color and slight variations that are inherent in live displays. This method, however, was essential for the production of time-reversed displays. The infants were required to sit through each of two conditions in which two events were presented to habituation in order to obtain measures for analysis of sensitivity to dynamics. The length of this session increased the likelihood that the infants would become tired and fussy.

Our criterion for exclusion was as follows: if an infant cried, the session was terminated; if an infant's fussiness was great enough so that he or she failed to remain seated facing the monitor, the data for that infant were dropped; finally, infants were excluded if an interaction occurred with the parent that influenced the infant's looking. For example, if the parent attempted to calm the infant during the experiment by jiggling his or her knee or holding the infant in a standing position to terminate the fussiness, the data were dropped because the onset of these behaviors was found to increase looking time for the subsequent trial. In the end, data of 12 infants (6 boys and 6 girls) were collected and analyzed in the rigid event condition. These infants ranged in age from 7 months, 22 days to 8 months, 7 days (M = 7 months, 28 days). The data of 12 infants were also analyzed in the nonrigid event condition (7 boys and 5 girls). Their ages ranged from 7 months, 24 days to 8 months, 16 days (M = 8 months, 2 days).

Display generation. The three displays used in this experiment were video recordings of a ball rolling, water splashing, and a puppet swinging out from behind a barrier (see Figure 2). The events were recorded using a Panasonic video camera, and kinematic analyses of the motions in each event were performed using a peak performance system. The first rigid event (a nonreversible rolling ball) consisted of a ball (0.75 cm in diameter) appearing initially on the left side of the screen and then hit by a cue stick (as a billiard ball would be hit) so that it rolled to the right and came to a stop. The ball was then hit back to the left by another stick so that it returned to its original starting position. The table and background were covered in black cloth. The ball, also painted black, was covered with irregular patches of retroreflective tape that made the rotational motion of the ball salient. Both cue sticks were made of a light colored wood. Only the tips were visible on both the left and right edges of the display during the entire event. The event was recorded from the side, perpendicular to the path of motion at the level of the ball on the table. The duration of the event was 3.13 s.

The rolling ball event was carefully chosen for the qualitative properties of its trajectories. First, the path was symmetric. The starting position of the ball was also the ending position, and the path remained the same whether run forward or backward in time (right to left to right). However, the event's velocity profile was not symmetric, so when run forward, the instantaneous velocity at each point along the path was different from that when run in reverse. These velocities were obtained by tracking three of the white patches on the ball using a Peak Performance system. These patches were chosen because they remained in view during the ball's trajectory, unlike other patches that became occluded and unoccluded as the ball rolled (for extended analyses of the kinematics and optics of a rolling ball, see Bingham, 1995). The data were digitally filtered using a Fourier-based algorithm, and then differentiated using a central difference computation. In the top velocity profile of Figure 3, the average speed of the rolling ball was plotted as a function of the position in the x direction (in screen units). If the event was the same forward and reversed, the black and open lines would overlap.[2] In the bottom velocity profile of Figure 3, the speed was plotted as a function of time, so the first peak represents the ball's movement from right to left and the second peak from left to right. Following the curve from left to right, the peak velocity of the ball in the forward event occurs with the impact at the beginning of each motion. In each instance the ball then slowly rolls to a stop. Conversely, following the curve from the right to the left so that it is running reversed in time, the ball gradually accelerates to its peak velocity and then abruptly stops.

The second event ("splash") was filmed looking directly down into bucket of water. The surface of the water was covered with white patche of paper each outlined in black so as to keep areas of high contras separated for purposes of subsequent measurement and analysis of th display. During the event, a clay ball (approximately 2 cm in diameter) wa dropped into the center of the water causing a splash and subsequen oscillations. The display included the continued decreasing oscillations, bu ended before the patches had completely settled. The sides of the bucke were not visible in the display, and the patches on the water surface fille nearly the entire screen. The display had a duration of 4.13 s.

Unlike the rolling ball event, the splash event did not yield symmetr paths. The surface patches did not end in the same positions as they we before the clay ball was dropped. The precise path of motion for a samp of the patches is shown in Figure 4. As can be seen in the figure, motio

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[2] The three patches that were sampled did not fall directly on t centroid of the ball. Thus, their average speed is only an approximation the ball's true speed. This accounts for the lack of a smooth linear decrea in velocity.

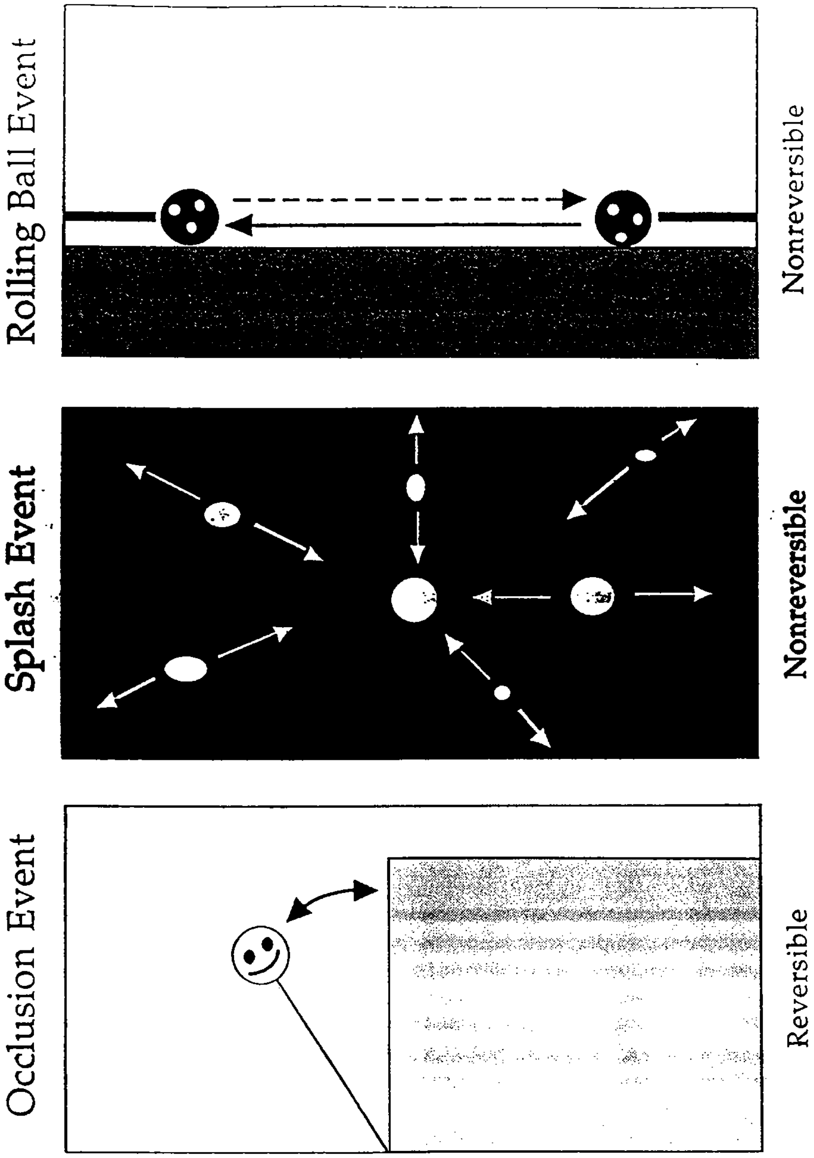

Figure 2. Schematic drawings of the three event displays used in this experiment: a rolling ball, splash, and occlusion; events are shown as they appeared on the television monitor.

was much more complex. Patches oscillated in different directions, exhibiting repeated increases and decreases in velocity. Nevertheless, the velocity profiles were not symmetric in time. The trajectory forms of the oscillations were different when run in reverse. The changes were more gradual and more subtle, involving a progressive decrease in the peak and mean velocities of oscillation. The top graph in Figure 5 shows the speed plotted against position for a single patch in the display for the entire 3 s of movement (approximately 1.00 s of the 4.13-s display consisted of the stationary patches before the ball impacted the water). As can be ascertained from the figure, the path over which the patch oscillates with the water's movement is not stable or constant. The bottom graph in Figure 5 shows the decrease in velocity of the patch's oscillations over time. In this display there were two differences between the forward and reversed events, both path asymmetry and velocity profile asymmetry. Given the complexity of the event, the spatial asymmetry may not be salient. The temporal asymmetry may also have been less salient as noted, in part because the patches never actually came to rest. As a result, we expected greater difficulty in discriminating the forward and reversed versions of this event.

The final event ("occlusion") consisted of a styrofoam ball (7.5 cm in diameter) on the top of a stick that swung out like an inverted pendulum from behind a light blue cardboard wall. The background to the side of the wall was black. The styrofoam ball was white and had colorful pieces of clay attached in the form of a smiling face. During the event, the head swung out from behind the wall into view, and then swung back behind the wall. It was filmed directly in front at the level of the head, with the blue occluding wall filling one third of the screen on the left. The event duration was 3.53 s.

Similar to the rolling ball event, the occlusion event exhibited a symmetric path. The starting point of the face when it became unoccluded was also the ending point when it became occluded again. However, unlike both the rolling ball and splash events, the velocity profile of the occlusion event was also symmetric, making the reverse of the event identical to the forward event (see Figure 6). The symmetry is evident in the overlap of the

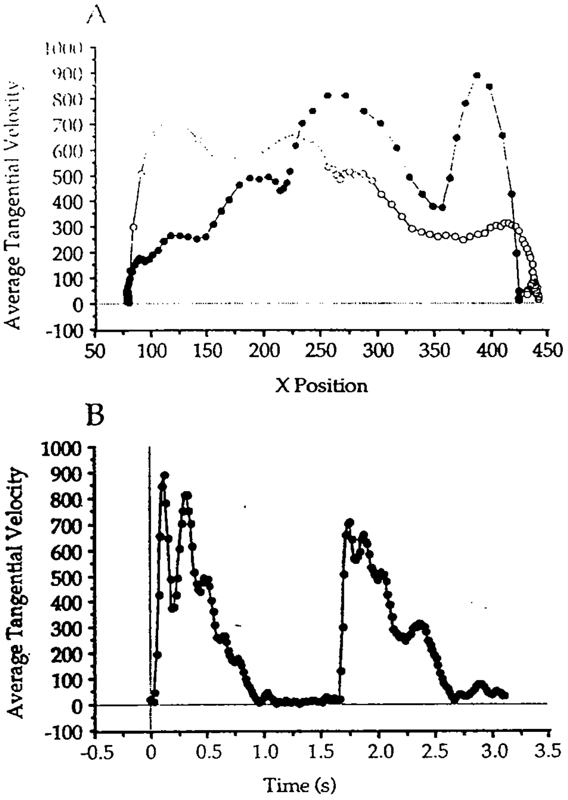

Figure 3. Graphs depicting the velocity profile of the rolling ball event. A: Average speed of three patches on the rolling ball as a function of the ball's position along the path (in arbitrary screen units). For the forward event, the black dots represent the velocity as the ball moves from right to left, and the open dots represent the ball's velocity as it moves back from left to right. For the reversed event, the opposite was true. The open dots show the ball's velocity during its movement from right to left and the black dots show the ball's velocity as it moves back from left to right. B: Average speed as a function of time.

velocity profiles (lack of complete overlap is due to noise in Peak Performance measurements and subsequent filtering). Thus, the velocity profiles should be identical and no difference should be detected between the forward and reversed occlusion events. When adults were presented with the forward and reversed occlusion events and asked to pick out the reversed display, they performed at chance (4 of 8 correctly identified the reversed occlusion event). Conversely, all of the adults correctly identified the reversed ball and splash events. The occlusion events were created as a control for the technologies used in reversing the displays. If the infants dishabituated to the reverse of the event after habituating to the forward event, then a technological confound must have been present that could also be responsible for any dishabituation in the other two events.

All three events were digitized and then reversed in time using the program Adobe Premier (1994). Frame rates and the event images were held constant during the reversal, so the only difference between the normal (forward) display and the reversed was the opposite ordering of the frames. Each display was then duplicated 20 times and recorded back onto separate videotapes with a 1-s interstimulus interval.

Apparatus. A chair was placed approximately 1.5 m in front of a 21-inch (53-cm) television monitor that could be seen through a hole in a black curtain. The curtain hung from the ceiling to the floor, blocking the remainder of the room from view. The center of the monitor was approximately level with the infant's eyes. A mirror was attached to the wall behind the left side of the infant's chair. The parent wore a pair of opaque glasses during the session to prevent him or her from seeing the monitor and influencing the infant's responses. A Panasonic video camera mounted directly over the monitor recorded the infant's face in addition to the display reflected in the mirror. Only the lens of the camera was visible through the curtain. The camera was connected to an electronic counter that fed into a combined Panasonic TV/VCR used for recording the image of the infant. The counter provided a measure of time that was recorded along with the infant and the display being shown to the infant. This TV/VCR was also used by the experimenter during the study to observe the infant's eye movements (corneal reflection) and to determine habituation.

Two Panasonic VCRs were connected to an AB switch that fed into the television monitor that the infants viewed. The AB switch allowed the experimenter to control which VCR signal went to the monitor during the session, and enabled the experimenter to switch between the forward and reversed display tapes rapidly.

The entire room was darkened except for a lamp in the corner of the room on the side of the curtain with the infant, which provided a low level of illumination.

Design and procedure. The infants were assigned to one of four groups. All groups viewed the occlusion event in addition to one of the experimental events (rolling ball or splash). The first group was habituated to the forward rolling ball event and upon habituation was switched to the reverse rolling ball event. The second group was first presented with the reversed rolling ball event and when habituated, was then shown the forward rolling ball event. The third group first saw the forward splash event and was then switched to the reversed splash event after habituation. The fourth group was habituated to the reversed splash event first and was then switched to the forward splash event. In all four of these groups, the occlusion event was presented with the same ordering (forward–reversed or reversed–forward) as was the experimental event. An habituation measure was used to assess sensitivity to the trajectory forms of these events. As is evident, the exact procedure used is not a standard habituation paradigm with a habituation event and two test events. We had one test event, which was compared with the habituation event. The method using two test events is primarily used as a means to control for confounding changes between the displays other than the property of interest. Our displays are entirely self-controlling, however, because the same video clip is used for both the forward and reversed events. Thus, we do not need the control of two test events. The only difference is time, which results in the different trajectory forms described previously. The property we are interested in studying, trajectory form, is the only possible difference between our displays. Therefore, if the infants are sensitive to this property, they will notice the difference between the two events. If the infants are not sensitive to that property, they should see the forward and reversed events as identical. Thus, we habituated the infants to the event in one direction, and then switched them to the other direction. An increase in looking time would be evidence for the infants' sensitivity to the change in trajectory forms. A similar design was previously used in the study by Spitz et al. (1993).

During the session, the infant sat on the parent's lap, directly facing the television monitor. A trial began when the infant faced the screen and fixated on the event. Corneal reflection (reflection of the light from the monitor on the infant's pupil) was used to assess when the infant looked toward or away from the display. When the infant looked directly at the television monitor, his or her eyes reflected the light. The habituation even (event display presented first) was repeated six times or until the infan looked away for 0.5 s. Thus, the infant could see a maximum of six even presentations on each trial (approximately 22.0 s). At the end of a trial, the tape was stopped, rewound, and then started again for the next trial. The minimum intertrial interval was 5.0 s, and averaged around 6.0 s. This procedure continued for that display until the habituation criterion was reached. The habituation criterion was met if the infant looked away fo 0.5 s before the third of six possible repetitions of the display in a trial fo two consecutive trials. Therefore, the infant's looking times must hav decreased to below the 8.0 s required for two presentations in each tria

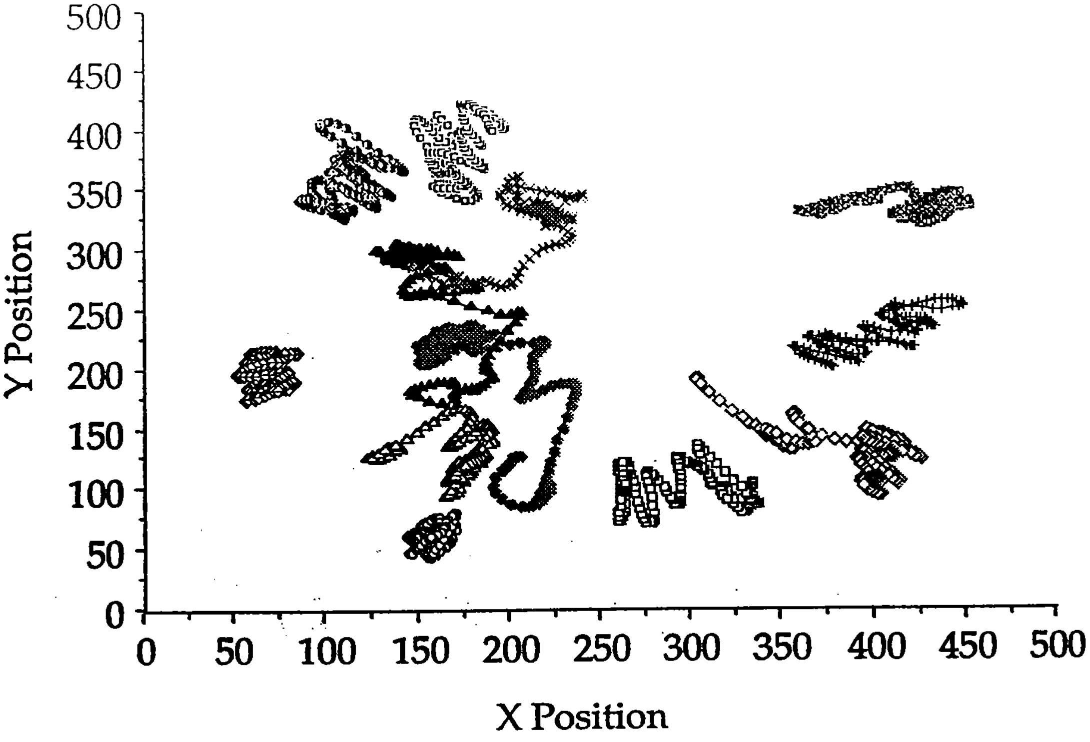

Figure 4. Paths of each patch on the surface of the water during the splash event. In the splash display, the paths of motion for a sample of individual patches are shown as they oscillate around in the *x,y* plane during the event. The position units are arbitrary screen units.

(each event presentation was 4.0 s in duration on average) for two consecutive trials. This method and criterion level were adopted from Oakes (1994) and Cohen and Oakes (1993).

The events in each session were divided into two phases: habituation to the first display and the switch to the test display. During the first phase, the infant was habituated either to the forward or reversed rolling ball or splash event using the method previously described. Once habituation occurred, the second phase began. At this point, the infant was switched to watching the test event: the first event (either rolling ball or splash) in the opposite direction (either reversed or forward). This phase continued until the habituation criterion was reached once again. After a short break, the same procedure was followed using the occlusion event. Pilot infants shown only the occlusion event exhibited no dishabituation to the reverse of the event, and thus the stimuli were determined to be free of technological confounds. However, because the occlusion event did not show any change when reversed, infants became fussier more easily. Therefore, in Experiment 1 the ball or splash events were always run first followed by the occlusion event to reduce the chance of fatigue and fussiness in the infants during the experimental events. No differences were found in looking times or length to habituation for the pilot infants shown the occlusion event first or the test infants shown the occlusion event second, indicating no difference in performance for the test infants.

The dependent measure was the length of the infant's first look per trial, and was assessed by corneal reflection. Two observers separately coded the data for 5 infants after the session was completed (using the counter recorded on the infant tapes) and had an interobserver reliability of .98. As a result of this high reliability, one observer was then used to code the remainder of the infant data. The counter on the tape provided an exact measure of looking time. Coders were instructed to record the time on the counter when the infant started looking at the display, and the time on the counter when the infant first looked away. This provided a nearly exact objective measure of total infant looking time. To further reduce observer bias during coding, the projection of the event being shown to the infant was covered so that the coders were unaware of the condition.

Results

The results are shown in Figure 7. First, a 3 × 5 mixed factorial analysis of variance (ANOVA) was conducted with condition as the between-subjects variable (ball, splash, or occlusion), and trial as the within-subjects variable (first trial and four trials prior to display switch). The ANOVA was conducted to test for habituation across trials and if habituation was found to have occurred, whether the pattern of habituation was the same for the three conditions. Both the forward-first and reversed-first groups were combined for analysis. The ANOVA revealed a main effect for trial, $F(4, 180) = 122.72$, $p < .001$, no main effect for condition, $F(2, 45) = 0.65$, $p > .05$, and no interaction, $F(8, 180) = 1.05$, $p > .05$, indicating that habituation occurred in the same pattern for the infants in each condition. Looking times dropped from the first trial (ball, $M = 22.0$ s, $SE = 1.3$ s; splash, $M = 24.8$ s, $SE = 1.4$ s; and occlusion, $M = 24.21$ s, $SE = 1.04$ s) to the last trial just prior to switching to the opposite display (ball, $M = 5.88$ s, $SE = 0.41$ s; splash, $M = 3.5$ s, $SE = 0.56$ s; and occlusion, $M = 4.10$ s, $SE = 0.35$ s).

We then conducted a 3 (condition) × 4 (trial) ANOVA, to test whether dishabituation occurred. Trials included two trials prior to and two trials after the switch. There was a significant main effect for trials, $F(3, 135) = 19.50$, $p < .001$, and condition, $F(2, 45) = 31.60$, $p < .001$, as well as a significant interaction, $F(6, 135) = 16.90$, $p < .001$. To explore these differences, we conducted *t* tests

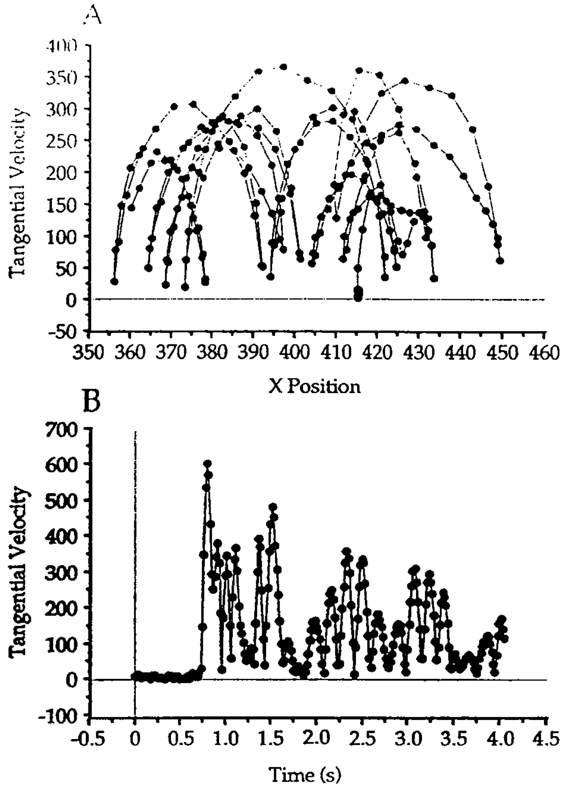

Figure 5. Graphs depicting the velocity profile of the splash event. A: Speed of a single patch in the splash display as a function of position in arbitrary screen units. B: Speed of the same patch plotted as a function of time.

comparing the looking times on the trial prior to and after the switch to the novel display. The results indicated that infants in both the rolling ball and splash conditions dishabituated when presented with the opposite display: ball, $t(11) = 9.70$, $p < .001$; splash, $t(11) = 3.10$, $p < .01$. The t tests on both occlusion event control conditions (one each for the ball and splash groups) revealed no dishabituation, $t(11) = 0.40$, $p > .05$ (occlusion event seen by ball group), and $t(11) = 0.70$, $p > .05$ (occlusion event seen by splash group). These results also showed that no technological confounds were present in our displays. The infants were not able to tell the difference between the forward and reversed occlusion displays.

To test whether the amount of dishabituation was different between the conditions, we conducted a second ANOVA on the difference scores (looking time on the trial immediately following the display switch minus looking time on the last habituation trial before the switch). This ANOVA allowed us to tell whether the amount of change in looking time between displays was different for the two event conditions. The ANOVA was significant, $F(1, 22) = 37.05$, $p < .001$, indicating that the rolling ball and splash conditions did not have the same increase in looking time when switched to the novel display. The magnitude of change in looking time was significantly greater for the rolling ball event (an increase of 14.5 s) than the splash event (an increase of 4.7 s). Infants exhibited a greater increase in looking time in the rolling ball condition than in the splash condition. This difference might have occurred because the infants found the rolling ball event to be more interesting. However, if this was the case, the looking times should have been different when the infants first encountered each type of event. However, a t test comparing the looking times for the first splash trial compared to the first rolling ball trial (using data from both forward and reversed versions in each case) failed to reach significance, $t(22) = -1.67$, $p > .1$. Also the mean for the splash (24.7 s) was somewhat larger than for the rolling ball (21.1 s). So, the difference in dishabituation looking times could not have been the result of simple preference for one of the two events.

We also investigated whether infants were sensitive to the lawful difference between the forward and reversed displays. To determine this, we first tested differences in number of trials to habituation for the forward versus reversed display when each of these was shown first. If the infants experienced the reversed display as strange, different, or impossible, we might expect them to require more trials to habituate. On the other hand, if they found the possible event to be more interesting, then we might expect them to require more trials to habituate. We found no differences in the number of trials to reach habituation for the rolling ball forward and reversed displays, $t(10) = 0.12$, $p > .05$, or the splash

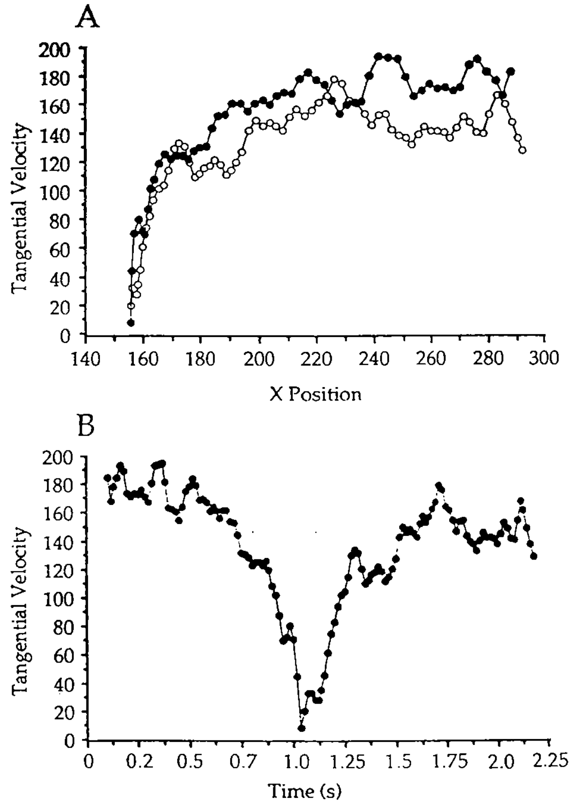

Figure 6. Graphs depicting the velocity profile of the occlusion event. A: For the occlusion event, the speed of the puppet's head as a function of position (in arbitrary screen units). The black dots represent the movement from the right to left (as it becomes unoccluded), and the open dots represent the movement from the left to right as it becomes occluded again. The opposite is true for the reversed occlusion display. The open dots represent the movement from right to left as it becomes unoccluded, and the black dots represent the movement back to the right as it becomes occluded again. B: Speed as a function of time.

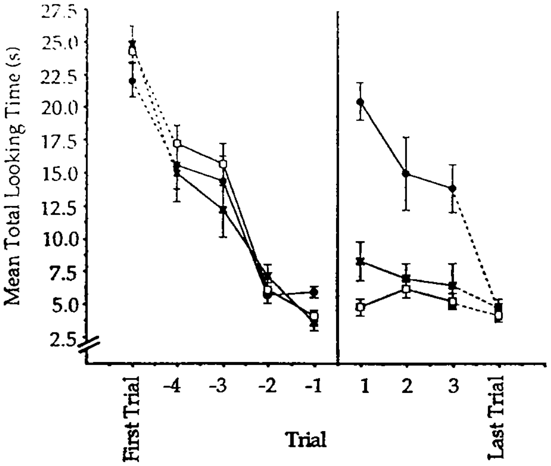

Figure 7. Graph of results for Experiment 1. The mean total looking times in seconds for the three event conditions in Experiment 1 are shown for the first trial, for the four trials prior to the switch to the novel display, for the three trials immediately after the switch, and for the last trial. The groups presented with the forward display first and the reversed display first are combined for each event. The black circles represent the looking times for the rolling ball event, the Xs represent the looking times for the splash event, and the open squares represent the looking times for the occlusion event. Error bars represent standard error.

forward and reversed displays, $t(10) = 0.89$, $p > .05$. For each event we also tested to determine whether there was a significant difference in the number of trials needed to reach the habituation criterion when the infant was switched to either the forward or reversed event. Again we found no differences: $t(10) = 0.28$, $p > .05$, for the rolling ball event, and $t(10) = 0.61$, $p > .05$, for the splash event. Differences in amount of looking time when presented with the novel versus familiar displays have often been used to test for infant perceptual sensitivity (e.g., Benasich & Tallal, 1996; Pecheux & Lecuyer, 1989; Premack & Premack, 1997). We thus tested for differences in amount of total looking time per trial for the forward and reversed events when presented as the novel display after initial habituation to the opposite direction. There were no significant differences between the forward and reversed displays for either the rolling ball, $t(10) = 0.51$, $p > .05$, or the splash events, $t(10) = 1.42$, $p > .05$. None of the previous tests revealed any significant differences. Thus, we found no evidence that the infants perceived any dynamical differences between the forward and reversed events.

Experiment 2

The results of Experiment 1 indicated that 8-month-old infants are sensitive to changes in the trajectory form of the rigid rolling ball and nonrigid splash events. To further test for the stability of this finding, we ran a partial replication of Experiment 1. This potentially allowed us not only to replicate the findings of Experiment 1, but also to rerun the statistical tests for sensitivity to the dynamics using more subjects, thus increasing the power. We tested infants only on the rolling ball and occlusion displays, and always ran the occlusion display first to counterbalance the order in Experiment 1.

Method

Participants. Twenty 8-month-old infants were recruited to participate in this study by phone. The data of 8 infants were dropped due to extreme fussiness, using the same criterion as in Experiment 1. Therefore, the data for 12 infants (7 boys and 5 girls) were retained. These infants ranged in age from 7 months, 27 days to 8 months, 7 days (M = 8 months, 3 days).

Apparatus, design, and procedure. The experimental apparatus was identical to that used in Experiment 1. The same overall design and procedure were used, with a few exceptions. First, infants were tested on the rolling ball and occlusion conditions only. As in Experiment 1, half of the infants were habituated to the forward display first and the other half were habituated to the reversed display first. However, in this experiment all the infants viewed the occlusion condition first and then the rolling ball condition. This contrasts with Experiment 1 because those infants all viewed the rolling ball condition first. The rest of the procedure was identical to that used in Experiment 1.

Results

The results of Experiment 2 are shown in Figure 8. We conducted a 2 × 5 mixed factorial ANOVA. The condition (ball or occlusion) was the between-subjects variable, and trial (first trial and four trials prior to display switch) was the within-subjects variable. There was a main effect for trial, $F(4, 88) = 45.31$, $p < .001$, no main effect for condition, $F(1, 22) = 0.00$, $p > .05$, and no interaction, $F(4, 88) = 1.30$, $p > .05$. These findings indicate that the same pattern of habituation occurred for both conditions. Looking times dropped from the first trial (ball, $M = 20.0$ s, $SE = 1.76$; occlusion, $M = 21.07$ s, $SE = 1.70$ s) to the trial just prior to the switch to the opposite display (ball, $M = 4.62$ s, $SE = 0.73$ s; occlusion, $M = 5.56$ s, $SE = 0.57$ s).

To test whether dishabituation occurred when the infants were switched to the novel display, we conducted a 2 (condition) × 4 (trial) ANOVA. As before, trials included the two trials prior to and two trials immediately following the switch to the novel

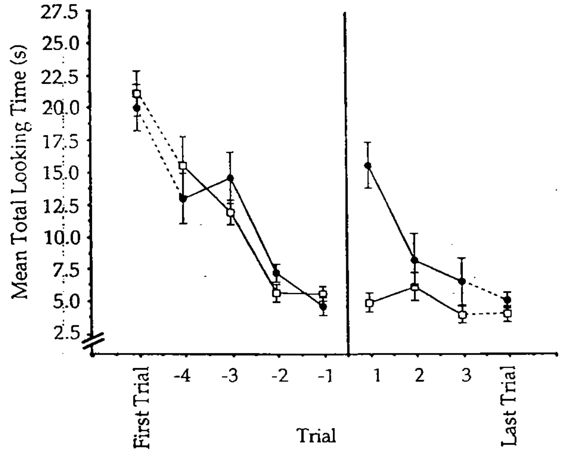

Figure 8. Graph of results for Experiment 2. The mean total looking times in seconds for the two event conditions in Experiment 2 are shown for the first trial, for the four trials prior to the switch to the novel display, for the three trials immediately following the switch, and for the last trial. The groups presented with the forward display first and the reversed display first are combined for each event. The black circles represent the looking times for the rolling ball event, and the open squares represent the looking times for the occlusion event. Error bars represent standard error.

display. There were significant main effects for trials, $F(3, 66)$ 9.39, $p < .001$, and condition, $F(1, 22) = 9.44$, $p < .01$, as well as a significant interaction, $F(3, 66) = 12.88$, $p < .001$. The t tests comparing looking times on the trial prior to and after the switch indicated that infants in the rolling ball condition dishabituated to the opposite display, but did not show dishabituation in the occlusion condition: ball, $t(11) = 6.72$, $p < .001$; occlusion, $t(11) = 0.78$, $p > .05$. These results replicated the previous finding that infants are sensitive to the differences between the forward and reversed rolling ball display. Furthermore, it replicates the finding that there were no technological confounds in the displays. Because the infants were shown the occlusion event first, and dishabituation was observed in the rolling ball condition, this result could not have been due to fatigue.

To determine if infants recognized the reversed display as impossible, we used the same measures as in Experiment 1. There was no difference in the number of trials it took to reach habituation between the forward and reversed rolling ball displays, $t(10) = 0.32$, $p > .05$. There was also no difference in the number of trials needed to reach the habituation criterion after being switched to the novel display, $t(10) = 0.50$, $p > .05$. We also performed both of these tests using the combined data of Experiments 1 (ball condition only) and 2, so that the number of infants used in the test was doubled from 12 to 24. Even with this increase in power, no differences were found between the number of trials to achieve habituation for the initial presentation of forward and reversed displays, $t(22) = 0.32$, $p > .05$, and the number of trials to reach habituation after being switched to the novel display, $t(22) = 0.11$, $p > .05$. The slope of the relation between trial number and looking time (i.e., a measure of rate of habituation) has also been used to evaluate infant perceptual sensitivity (e.g., Benasich & Tallal, 1996; Pecheux & Lecuyer, 1989; Schiff et al., 1989).

We combined the data from Experiments 1 and 2, and recorded looking times for the forward and reversed rolling ball displays for every trial during initial habituation and used simple linear regression to derive the slope of the relation between trial number and looking time for each infant. We then tested for a difference in slope between the forward and reversed events using an unpaired t test, but the result did not reach significance, $t(22) = 1.70$, $p = .10$. As in Experiment 1, we also tested to see if there were any differences in the amount of total looking time for the trial immediately following the switch to the novel display. We first conducted the t test only on the infants in Experiment 2. There was no difference in total looking time for the forward and reversed events, $t(10) = 0.60$, $p > .05$. Using the combined data from Experiments 1 and 2, we conducted another t test and again found no difference in looking times, $t(22) = 0.85$, $p > .05$. These findings for both Experiment 2 and the combined data of Experiments 1 and 2 all replicate those of Experiment 1, which fail to provide evidence that infants perceive any dynamical differences between the forward and reversed events.

General Discussion

The first question we investigated was whether 8-month-old infants are sensitive to trajectory forms. The results indicate that they are. When switched between forward and reversed versions of the events, the infants dishabituated, and did so both when switched from forward to reversed and from reversed to forward. However, the infants exhibited a larger increase in looking time when switched to the novel rolling ball event than the novel splash event, as can be seen by the significantly larger mean looking time for the first dishabituation trial. We tested looking times for the first trials during habituation to see whether the rolling ball event might simply have been more interesting to the infants. The results showed that this was not the case. We expected the temporal asymmetry of the splash event to be less salient, in part because the relative decrease in velocity in the splash event as compared with the rolling ball event was less. The decrease in each event was calculated as follows. First, we calculated the mean velocity (in screen units) of the first 0.5 s of movement in the display and the mean velocity of the last 0.5 s of movement in the display. Second, we took the difference between these two values. Third, we divided the difference by the mean velocity of the entire event. This Weber fraction yielded the relative amount of change in velocity over the course of the event. This measure showed that there was clearly less change in the splash display (0.664 s) than in the rolling ball display (2.18 s), meaning that the rolling ball event slowed down more than the splash event. We compared the proportion of the velocity change in the two displays to the amounts of dishabituation that occurred when infants were switched to the novel event in each case. The ratio of the amounts of dissipation in the rolling ball and water displays was 2.18:0.664 s (or 3.28:1), whereas the ratio of infant dishabituation was 15.25:4.7 s (or 3.24:1). The near equivalence of these proportions suggests that the relative strength of the dishabituation could be a function of the relative changes in velocity over the course of the two events, respectively.

Whereas amount of change in velocity could account for the differences in the looking time for the novel rolling ball and nove splash events, other factors in the displays also could also have ha an effect. First, in the rolling ball event, the ball moved across th screen, enabling the infants to track it with their eyes. The patche in the splash display, however, covered the entire television screen and moved in different directions making it impossible to track th movement. By viewing the videotape of the infants, it was clea that in the majority of the cases the infants were tracking th rolling ball. No obvious tracking was visible in the splash condition. The lack of a single object to fixate and track in the splas event could make it harder to detect the differences in the motion of the forward and reversed events if the infants were busy scanning the display, looking at different portions at different time Due to this added complexity in the nonrigid event, it is possibl that infants simply were not as sensitive to the changes in trajectory form. Nevertheless, the infants did dishabituate to the splas event, indicating some sensitivity to the trajectory form of th nonrigid event.

The second question we investigated was whether 8-month-ol infants are sensitive to the dynamics of the forward and revers events. Although the results of these experiments show th 8-month-old infants are sensitive to trajectory forms, there is evidence of sensitivity to the underlying dynamical difference The infants did not react to the reversed/impossible event especially odd or surprising, or to the possible event as mo interesting because more expected. It took just as long for t infants to habituate to the reversed event as to the forward eve as well as to rehabituate after the presentation was switched to t opposite/novel event, and they habituated at the same rates. addition, the infants dishabituated by the same amount to t forward and reversed displays. Given the mere lack of evidence, we cannot conclude that the infants were not sensitive to the dynamics, nor can we conclude that they were sensitive. We can only conclude that the salience of the difference relative to their sensitivity and attentiveness was not enough to yield an effect. This result is noteworthy, however, because the reversed displays looked distinctly odd to adults. When asked to rate the "weirdness" of each display, the adults rated the reversed rolling ball and splash displays as significantly more weird than their forward counterparts: rolling ball, $t(7) = 4.53$, $p < .01$; splash, $t(7) = 3.32$, $p < .05$. This outcome raises the possibility that one might obtain evidence that the difference is detected by older infants, but this remains to be investigated.

Although we failed to find any evidence that infants recognized the lawful difference between the displays, we did have clear evidence that the infants noticed the differences between the two displays. They detected the differences in trajectory forms, which suggests that in some previous studies of perception of events, the infants may have responded to a change in trajectory form, and not to the physical or dynamical character of the events. In such studies, for example, collision events have been used to examine how infants respond to differences in the sizes of the objects versus length of the path of travel, or how barriers between the two objects affect the movement of the second object (Kotovsky & Baillargeon, 1995), or how contact and lack of contact between the two objects affects infant fixation times (Cohen & Oakes, 1993). The results in these studies all suggested that infants were sensitive to the physical impossibility of the events. The problem is that the trajectories were not controlled in the displays. In some of the displays, the objects were released and allowed to act on the other objects naturally, whereas in comparison displays, the objects were manipulated by hand. These studies did not provide any analysis of the trajectory forms of the moving objects. It is therefore impossible to know just how different the trajectory forms were between the habituation and test events used, and whether any differences could account for the results in those studies. However, there remain other studies on this issue where trajectories were better controlled and could not have been confounded with the variables of interest (e.g., Kim & Spelke, 1992; Spelke et al., 1992).

To conclude, we found that 8-month-old infants are sensitive to changes in trajectory forms in events. The result means that the dynamically determined forms of motion in events could be used by infants at this age to discriminate among and identify events. However, we found no evidence that the infants were sensitive to the underlying dynamics of these events.

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Received March 13, 1998
Revision received November 17, 2000
Accepted November 20, 2000 ■