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Infants' Sensitivity to Effects of Gravity on Visible Object Motion

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A preference method probed infants' perception of object motion on an inclined plane. Infants viewed videotaped events in which a ball rolled downward (or upward) while speeding up (or slowing down). Then infants were tested with events in which the ball moved in the opposite direction with appropriate or inappropriate acceleration. Infants aged 7 months, but not 5 months, looked longer at the test event with inappropriate acceleration, suggesting emerging sensitivity to gravity. A further study tested whether infants appreciate that a stationary object released on an incline moves downward rather than upward; findings again were positive at 7 months and negative at 5 months. A final study provided evidence, nevertheless, that 5-month-old infants discriminate downward from upward motion and relate downward motion in videotaped events to downward motion in live events. Sensitivity to certain effects of gravity appears to develop in infancy.

Human adults are sensitive to a variety of effects of gravity on the motions of visible objects. For example, an object that falls freely appears to move naturally only if it speeds up (Shanon, 1976), and an object that is dropped from a moving carrier appears to move naturally only if it moves downward on a parabolic path (Kaiser, Proffitt, Whelan, & Hecht, in press). These accurate perceptions are striking, because many adults are prone to error if they must judge the path or acceleration of an object whose motion is not directly visible (McCloskey, 1983; Shanon, 1976). Adults appear to be more sensitive to physical constraints on object motion when they see moving objects than when they reason about them.

What is the basis of this sensitivity? Does human perception embody a general gravity principle (e.g., that objects are subject to a downward attraction), or does it depend on a collection of expectations about the behavior of objects in particular situations (e.g., that objects move downward when released in the air)? How, moreover, does sensitivity to the effect of gravity arise? Do humans learn about the natural motions of objects, or are humans innately predisposed to perceive object motion in relation to gravity? Animals have evolved a variety of mechanisms that take account of the effects of gravity on self-motion (Howard, 1982; Schöne, 1984); sensitivity to the effects of gravity on object motion might have evolved as well. These questions motivated the present research with young infants.

In the experiments we used a preferential looking method to investigate infants' reactions to events in which a fully visible object moved naturally or unnaturally on an inclined plane. Infants were presented with videotaped events in which a ball rolled downward or upward on an inclined plane while speeding up or slowing down. In Experiments 1 and 2 we investigated the sensitivity of 5- and 7-month-old infants to the effect of gravity on the ball's acceleration. In Experiment 3 we focused on the sensitivity of 5- and 7-month-old infants to the effect of gravity on the ball's direction of motion. In a final experiment we investigated 5-month-old infants' perception of the direction of object motion in live and videotaped events.

Experiment 1

Seven-month-old infants were habituated to one videotaped event in which a ball either rolled upward on an inclined plane with steadily decreasing speed or rolled downward on an inclined plane with steadily increasing speed (natural motion). Then infants were shown two test events in which the ball rolled on a plane inclined in the opposite direction (Figure 1). In one event, the ball moved with appropriate, downward acceleration: The downward-moving ball sped up and the upward-moving ball slowed down. In the other event, the ball moved with inappropriate upward acceleration: The downward-moving ball slowed down and the upward-moving ball sped up. Looking times to the test events were recorded and compared.

Predictions for this experiment follow from the assumption, documented in many studies using the habituation method, that infants will look longer at the event they perceive as more novel or surprising (Baillargeon, in press; Spelke, 1985). If 7-month-old infants understand that freely moving objects accelerate downward, then infants should look longer at the test event with the novel, upward acceleration than at the test event with the novel change in speed (from speeding up to slowing down or the reverse).

Method

Subjects. Subjects were full-term infants from the Ithaca, NY, area. Six girls and 10 boys participated in the experiment at ages ranging from 6 months, 15 days, to 7 months, 15 days (M = 7

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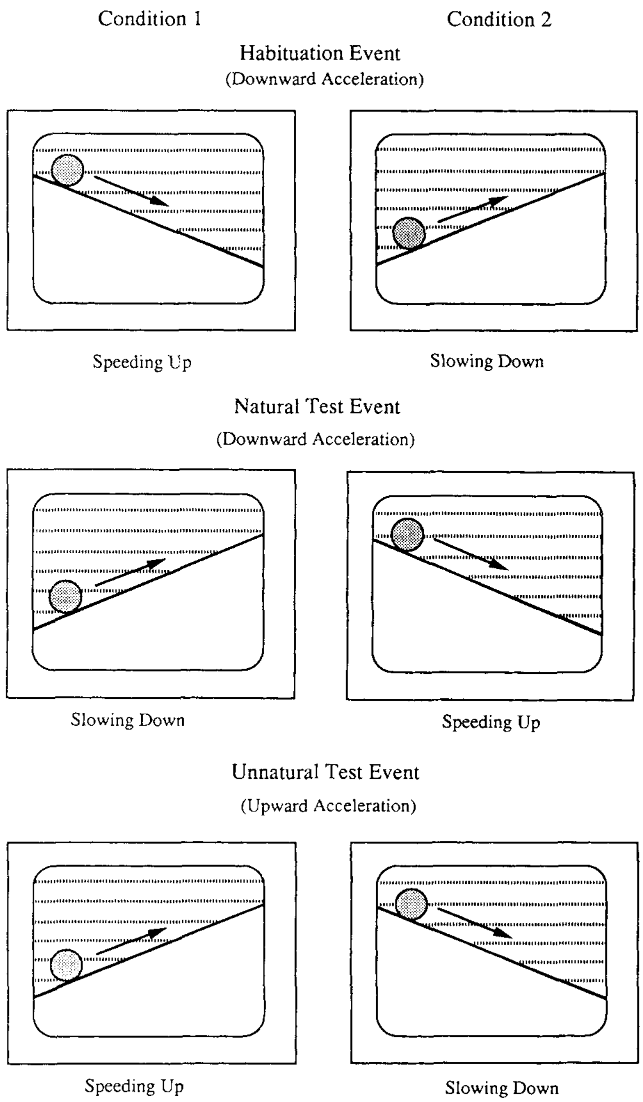

Figure 1. Schematic depiction of the habituation and test events for Experiment 1.

months, 4 days). Thirteen additional infants were eliminated from the experiment because of fussiness (12) or computer malfunction (1).

Displays. The events were videotaped in color and shown to infants on a 19-in. (48.3-cm) high-contrast color TV monitor. In all of the events, a white styrofoam ball decorated with colored spots and black stripes rolled downward or upward on a flat surface that was oriented 30° with respect to horizontal. Six parallel lines on the wall directly behind the table were orthogonal to the position of the camera such that they appeared to be horizontal on the screen.

Figure 1 depicts the four events used in the experiment. In the two downward acceleration events, the camera was oriented canonically, with its vertical axis aligned with gravitational vertical. One event presented the plane inclined 30° downward from left to right. The ball was released by a hand at the far left (upper) end of the plane and was caught at the far right (lower) end by a second hand. No force was exerted on the ball upon releasing it; gravity caused it to speed up. Upon catching the ball, the second hand returned it to the starting position, and the event was repeated.

The other downward acceleration event presented the plane inclined 30° upward from left to right. After the hand-held ball was placed at the far left (lower) end of the plane, a force was exerted on it (by means of an off-camera slingshot) to propel the ball up the incline. Although the force was not actually exerted by the hand, it appeared to adult observers that the hand propelled the ball upward. No further force was exerted on the ball, which steadily slowed down and came to rest at the upper end of the plane. There the ball was caught by the second hand and returned to the starting position.

The two upward acceleration events were the same as the downward acceleration events except that the parallel stripes and the camera were rotated 60° clockwise with respect to vertical. The effect of this rotation was to present the same arrangement of surfaces on the video screen as in the downward acceleration events but to have the ball accelerate upward. Thus, the ball that rolled upward steadily sped up and the ball that rolled downward steadily slowed down.

In all of the events, the average speed of the ball was 22.2 cm/s, the duration of the motion was 1.8 s, the interval between rolls was 4.0 s, and the length of the path of motion was 40 cm. At the infant's distance (60 cm from the center of the screen), the ball subtended 2.5° and it moved at an average speed of 20°/s.

Nine adults naive to the purpose of the present studies rated the naturalness of these four events. For each event, the motion of the ball was repeated four times. The events were shown in counterbalanced order across adults, within a larger set of nine displays of balls rolling upward, downward, or horizontally while speeding up, slowing down, or moving at a constant speed. After the last presentation of an event, an adult was asked to rate whether the motion appeared natural or unnatural on a scale from 1 (*very natural*) to 5 (*very unnatural*).

Figure 2 shows the average ratings for all nine events. All of the adults rated the two downward acceleration events as natural and the two upward acceleration events as unnatural. The ratings for each of these events differed significantly from the neutral rating of 3 (each $p < .05$, two-tailed sign test). When the object moved with increasing speed, its motion was rated as more natural when it moved downward ($SD = 0$); when it moved with decreasing speed, its motion was rated as more natural when it moved upward, $t(16) = 8.0$, $p < .001$.

Apparatus. The video monitor rested on one end of a table surrounded by a white curtain. The infant seat rested on the other end of the table facing the video screen. A white cardboard screen could be lowered in front of the video screen between trials. Two

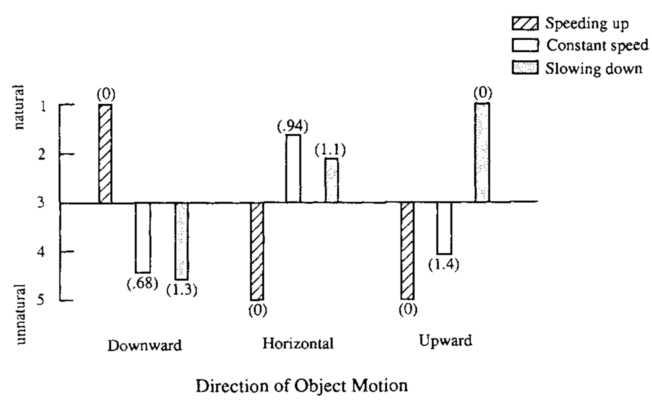

Figure 2. Adults' ratings of the naturalness of events in which a ball rolled upward, horizontally, or downward on a plane while speeding up, slowing down, or moving at a constant speed. (Means, and standard deviations in parentheses, are shown on a scale from 1 [*natural*] to 5 [*unnatural*].)

small holes in the curtain on either side of the monitor allowed observers to record infants' looking time by depressing buttons connected to a microcomputer. Observers could not see the videotaped events from these positions.

An experimenter, positioned behind the infant, controlled the presentation of events by operating the video recorder and by raising and lowering the screen. A small monitor allowed the experimenter to view the same display shown to the infant. A light activated by the primary observer's button indicated to the experimenter when the infant was watching the event.

Design. Half of the infants were habituated to the event in which the object moved downward while speeding up; they were tested with the events in which the object moved upward and either sped up or slowed down (Condition 1). The remaining infants were habituated to the event in which the object moved upward while slowing down; they were tested with the events in which the object moved upward and either sped up or slowed down (Condition 2). The two test events were presented three times each in alternation, with the order of test events counterbalanced across the subjects in each condition.

Procedure. After the infant was placed in the seat, the lights in the room were dimmed, the screen was raised to present the ball in its starting position, and observers began to record looking time. As soon as the infant observed the ball begin to roll (as judged by the experimenter, who viewed both the videotaped event and the light signaling the infant's looking time), the experimenter pressed a computer key and looking time began to be recorded on the computer. The event continued until the infant looked at the video screen for at least 0.5 s and subsequently looked away from the screen for 2 s continuously, at which time the computer signaled the end of the trial and the experimenter lowered the screen.

Two observers, blind to the experimental condition and the order of test events, measured the infant's looking time. Agreement between the observers was computed as the proportion of time both observers judged that the infant was or was not looking at the video screen. Interobserver agreement averaged .89.

The infant was presented with the habituation event repeatedly until 14 trials were presented or a criterion of habituation was met, whichever came first. The habituation criterion was a 50% decline in total looking time on 3 consecutive trials, relative to the total looking time on the first 3 trials whose total looking time equaled or exceeded 12 s (usually the first 3 trials).

When the habituation sequence ended, as signaled to the experimenter by the computer, the infant was given a short break if she or he appeared to be fussy. Then the infant was presented with the six test trials. The procedure was the same as for habituation, with one exception. If the infant did not look at the video screen during at least one complete motion of the ball on any given test trial, the test trial was immediately repeated and the new trial was substituted for the original trial. The decision to repeat a trial was made by the experimenter, who viewed the monitor and the light activated by the primary observer. This procedure ensured that every test motion was seen by the infant at least once.

Results

The mean looking times for the habituation and test trials are shown in Figure 3. Because looking times were positively skewed, they were converted to a log scale for analysis. Test trial looking times were analyzed by a 2 × 2 × 3 × 2 analysis of variance (ANOVA) with condition (1 vs. 2) and test order (natural event first vs. unnatural event first) as the between-subjects factors and with test trial pair and test event (natural vs. unnatural) as the within-subjects factors. This analysis revealed significant effects of test event, $F(1, 12) = 12.2$, $p < .005$, and test order, $F(1, 12) = 7.19$, $p < .05$: Infants looked longer at the event with unnatural acceleration, and those presented with the unnatural event first looked longer at the whole test sequence. These effects were complicated by an interaction of test event with condition, $F(1, 12) = 13.4$, $p < .005$, and by a triple interaction of test event, condition, and test order, $F(1, 12) = 6.37$, $p < .05$. The preference for the unnatural event was greater for the infants in Condition 1, who were tested with the upward direction of motion. Moreover, those in Condition 1 looked longer at the unnatural event regardless of the order of test events, whereas those in Condition 2 showed a greater preference for the unnatural event if it was presented first.

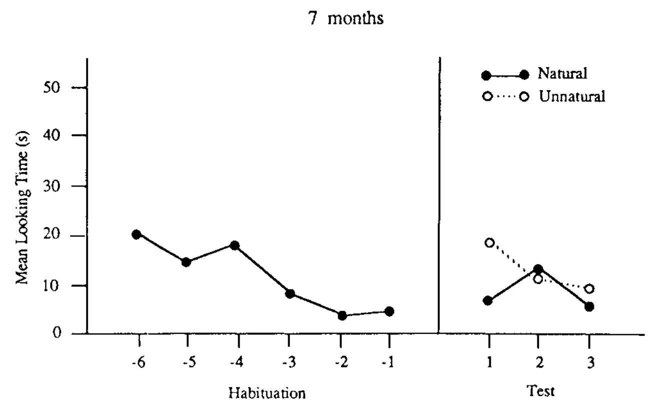

Figure 3. Looking time on the last six habituation trials and the six test trials of Experiment 1.

Discussion

After familiarization with an object moving downward with increasing speed, or upward with decreasing speed, infants tended to look longer at a test event in which the object moved in the other direction with the same change in speed (speeding up or slowing down) but a novel acceleration (upward). Infants evidently responded to a change in the direction of the object's acceleration, from natural downward acceleration to an unnatural upward acceleration.

The analysis suggests that the preference for the event with unnatural acceleration was shown primarily by the infants who were tested with motion in the upward direction. Looking preferences in a single condition of this experiment cannot be interpreted, however, because of the unknown baseline preference between events in which objects speed up versus those in which they slow down. In the absence of any response to the naturalness of object motion, infants might have an intrinsic preference for events in which objects move progressively faster. Such a preference would enhance infants' looking preference for the unnatural event in the upward test condition and attenuate that preference in the downward test condition. Unfortunately, it is not possible to assess intrinsic preferences for increases versus decreases in speed with the present events, because one can never eliminate the potential effect of perceived naturalness on infants' looking time.

Nevertheless, infants' overall looking preference for the event with unnatural acceleration cannot be explained in terms of any intrinsic preference between events in which objects speed up versus those in which they slow down, because each of these motion patterns was natural for half of the infants and unnatural for the others. We conclude that 7-month-old infants looked longer at the event with inappropriate acceleration because they were sensitive to its novelty or unnaturalness.

Experiment 2

In Experiment 2 we investigated the earlier development of perception of these events. We presented the events of Experiment 1 to a group of 5-month-old infants and used the same preferential looking procedure.

Method

The method was the same as in Experiment 1. Participants were 16 infants, 7 girls and 9 boys, ranging in age from 4 months, 15 days, to 5 months, 15 days (M = 5 months, 4 days). Nine additional infants were eliminated from the experiment because of fussiness (8) or computer malfunction (1). Interobserver agreement averaged .91.

Results

Mean looking times during the habituation and test trials are shown in Figure 4. Test trial looking times again were positively skewed; they were log transformed and analyzed as in Experiment 1. This analysis revealed a significant effect of test event, $F(1, 12) = 38.28$, $p < .001$: Infants looked longer at the *natural* test event. The only other significant effect was a main effect of test trial pair, $F(1, 12) = 4.52$, $p < .05$: Looking time declined over successive pairs of test trials.

A further analysis, with the additional between-subjects factor of age, compared the test trial looking preferences of the infants in Experiments 1 and 2. The analysis revealed a significant Age × Test Event interaction, $F(1, 24) = 38.61$, $p < .001$, reflecting the reversal, from 5 to 7 months, from preference for the natural test event to preference for the unnatural test event. This interaction was complicated by a triple interaction of age, test event, and condition, $F(1, 24) = 16.64$, $p < .001$. Whereas 5-month-old infants preferred the natural event whether the object sped up or slowed down, 7-month-old infants preferred the unnatural event more when the object sped up. In addition, the analysis revealed significant main effects of age, $F(1, 24) = 5.11$, $p < .05$, and of test trial pair, $F(2, 48) = 4.83$, $p < .02$: Five-month-old infants had longer overall looking times than 7-month-old infants, and the looking times of all infants declined over successive pairs of test trials. Finally, there were interactions of test event and condition, $F(1, 12) = 4.64$, $p < .05$, and of test event, condition, and test order, $F(1, 24) = 7.89$, $p < .02$. These interactions reflect a tendency for infants of both ages to look longer at the test events in which the object sped up and for infants tested with motion in a downward direction to look longer at whichever test event was presented first.

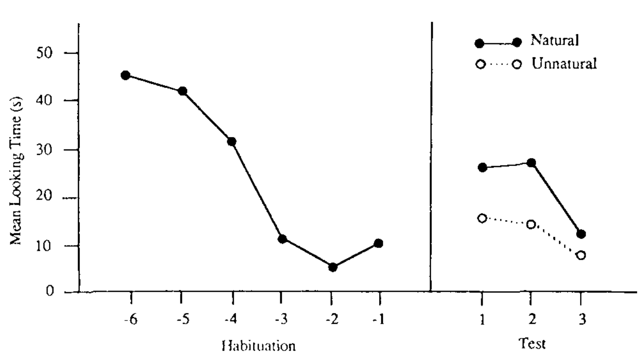

Figure 4. Looking time on the last six habituation trials and the six test trials of Experiment 2.

Discussion

After familiarization with an object rolling on an inclined plane with appropriate, downward acceleration, 5-month-old infants looked longer at a test event in which the object rolled in the opposite direction with a novel change in speed (from speeding up to slowing down or the reverse) than at a test event in which the object rolled with the familiar change in speed but a novel and inappropriate upward acceleration. Thus, infants responded primarily to the novelty or familiarity of an object's change in speed, not to the novelty or appropriateness of the object's acceleration in relation to gravity. The experiment provides no evidence that 5-month-old infants are sensitive to the effects of gravity on object acceleration.

The negative conclusion of this experiment derives from a positive finding: Five-month-old infants looked longer at the test event in which the object underwent a novel change in speed. Because the motions in the two test events had the same extent and average speed, the experiment provides evidence that the infants detected and discriminated the two motion patterns. When 5-month-old infants observe a ball rolling on an inclined plane, they evidently perceive whether it speeds up or slows down. Such infants do not appear to appreciate, however, that the object should speed up when it moves downward and slow down when it moves upward, in accord with the effect of gravity.

A comparison between the findings of Experiments 1 and 2 indicates that looking preferences between the natural and unnatural test events underwent a reversal between 5 and 7 months. This finding suggests that between 5 and 7 months of age, infants become sensitive to the effect of gravity on object acceleration. An alternative account of this finding may nevertheless be offered. Between 5 and 7 months, there may be a shift in infants' perception of changes in object motion. At 5 months, infants may be attuned primarily to an object's *change in speed* (i.e., its speeding up or slowing down). At 7 months, in contrast, infants may be attuned primarily to an object's *acceleration* (i.e., its change in speed in a given direction). Because the test events with downward acceleration presented a novel change in speed but the same acceleration as the habituation event, whereas the events with upward acceleration presented a new acceleration but the same change in speed as the habituation event, such a perceptual shift could account for the findings of Experiments 1 and 2.[1] Experiment 3 provides one means to distinguish these two possibilities. Infants were tested with a natural, downward acceleration event and an unnatural, upward acceleration event after habituation to a neutral, horizontal motion.

Experiment 3

The infants in this experiment were habituated to an event in which a ball underwent an initial rightward acceleration and then rolled rightward at a constant speed. Then the infants were shown the test events from Experiments 1 and 2, in which the ball was released at rest and moved with steadily increasing speed in a downward (natural) or upward (unnatural) direction (Figure 5). Looking times to the test events were compared. If infants are sensitive to the effect of gravity on object motion, then they should look longer at the test event with upward motion. In contrast, if infants respond only to the familiarity or novelty of an object's acceleration, then they should look equally at the two test events, whose accelerations differed equally from those of the habituation event.

Because each test event began with the ball at rest, in Experiment 3 we focused on what may be a simpler manifestation of the effect of gravity on object motion. Gravity determines the *direction* in which a stationary object begins to move. It seemed possible that 5-month-old infants would be sensitive to this effect of gravity. Thus, we conducted Experiment 3 with both 5- and 7-month-old infants.

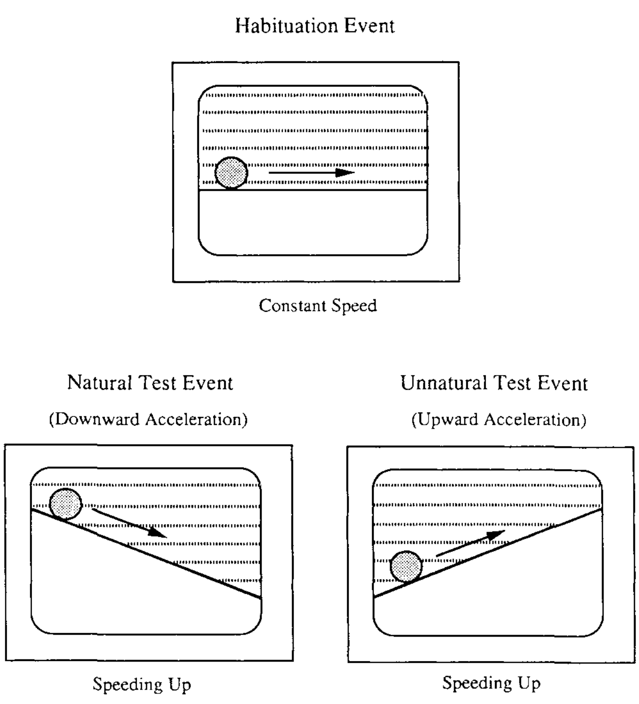

Figure 5. Habituation and test events for Experiment 3.

Method

The method was the same as in Experiments 1 and 2, except as follows.

Subjects. Participants were 8 infants at each of two ages. Three boys and 5 girls ranged in age from 4 months, 15 days, to 5 months, 15 days (M = 5 months, 0 days), and 3 boys and 5 girls ranged in age from 6 months, 15 days, to 7 months, 15 days (M = 7 months, 1 day). No infant failed to complete the experiment.

Displays. The displays are depicted in Figure 5. The test displays were the two events from Experiments 1 and 2 in which the ball moved with increasing speed in a downward or upward direction (i.e., with downward or upward acceleration). For the habituation display, the plane was slanted 3° downward, and both the camera and background stripes were rotated 3° clockwise so that the plane looked horizontal on the TV screen (the slight downward incline prevented the ball from slowing down because of friction). A slingshot, which was out of the camera's field of view, set the ball in motion on the plane. The ball rolled at the constant speed of 22.2 cm/s for 1.8 s. (Thus, its duration of motion, length of motion, and average speed were the same as in the events of Experiments 1 and 2.) This event was rated as natural by adults (see Figure 2), a rating that differed both from the neutral value of 3 ($p < .05$, two-tailed sign test) and from the ratings for both the downward constant speed event, $t(16) = 6.74$, $p < .001$, and the upward constant speed event, $t(16) = 4.0$, $p < .002$.

Design and procedure. All of the infants were habituated to the horizontal constant speed event and then were tested with the downward and upward acceleration events. The order of test events was counterbalanced across subjects. Interobserver agreement averaged .93.

Results

Mean looking times for the habituation and test trials are shown in Figure 6. Five-month-old infants showed no preference between the test events. A 2 (test order) × 3 (test trial pair) × 2 (test event: natural vs. unnatural) analysis of their log-transformed looking times yielded no significant effects. In contrast, 7-month-old infants looked longer at the upward acceleration event than at the downward acceleration event. The same analysis of their log-transformed looking times revealed a significant effect of test event, $F(1, 6) = 9.32$, $p < .05$.

A second ANOVA with the additional factor of age compared the test trial looking patterns of 5- and 7-month-old infants. This analysis revealed a significant Age × Test Event interaction, $F(1, 12) = 16.20$, $p < .005$: The older infants showed a reliably greater preference for the upward acceleration event. The only other significant effect was a Test Order × Test Event interaction, $F(1, 12) = 5.93$, $p < .05$: Infants looked longer at the test event presented second.

Discussion

The findings of Experiment 3 accord with those of Experiments 1 and 2. Seven-month-old infants looked longer at a test event in which the object was released and rolled upward

[1] We are grateful to Dennis Proffitt for suggesting this possibility to us.

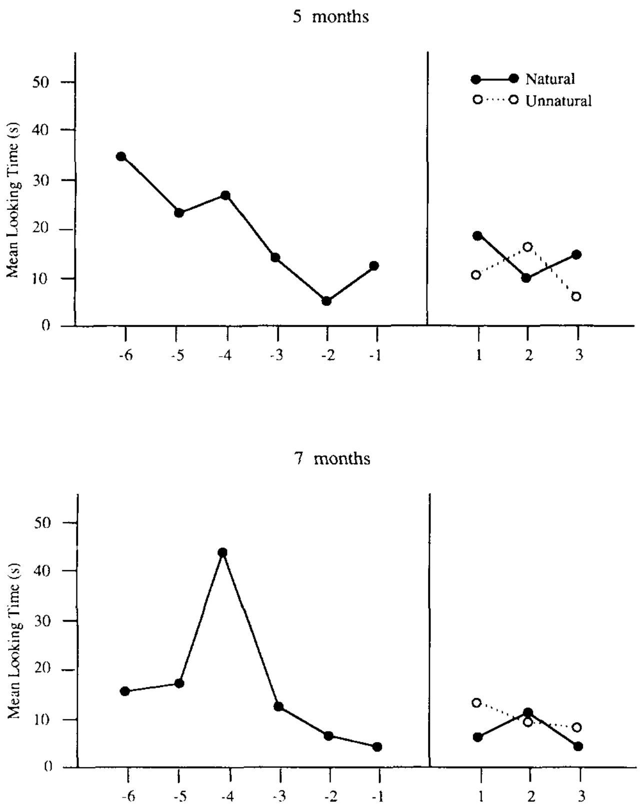

Figure 6. Looking time on the last six habituation trials and the six test trials of Experiment 3.

than at a test event in which the object was released and rolled downward. In contrast, 5-month-old infants looked equally at events in which an object was released at rest on a plane and rolled in a downward versus an upward direction.

Could these findings reflect an emerging baseline preference for upward motion? That possibility was investigated through a further analysis of the data from Experiments 1 and 2. In those experiments, infants were tested with two events presenting motion in either an upward or a downward direction. Because one event in each direction was natural, and one event in each direction presented an increase in speed, looking times to the two events in each direction were added together to obtain a baseline measure of preference for motion in an upward versus downward direction. A 2 (age) × 2 (direction: upward vs. downward) ANOVA was performed on these total looking times. This analysis revealed no significant effects: In particular, there was no interaction of age with direction of motion ($F < 1$). Separate analyses at each age confirmed that neither 7- nor 5-month-old infants showed any preference between upward and downward motion (both $Fs < 1$). No intrinsic preference for upward motion appears to emerge at 7 months.

The findings of Experiment 3 also cannot be understood in terms of a developmental shift from perceiving changes in speed (speeding up or slowing down) to perceiving acceleration. Both test events in this experiment presented an object that accelerated in a novel direction relative to the habituation event. At 7 months, however, infants looked longer at the test event in which the object accelerated upward. This preference provides evidence that 7-month-old infants are sensitive to some effect of gravity on object motion.

Experiment 3 provides no evidence that 5-month-old infants are sensitive to any effects of gravity in this situation. It is unlikely that the negative finding at 5 months stems from limitations of the habituation method or from deficiencies of the test displays, because of the findings of Experiment 2. That experiment used the same method and subject population as Experiment 3, and it presented two of the same test events. In that experiment, however, infants showed a significant preference between the test events, looking longer at the event in which an object's motion changed from speeding up to slowing down or the reverse.

Nevertheless, one aspect of the present displays could account for 5-month-old infants' failure to respond to the naturalness of these events. In order to perceive the downward acceleration event as natural and the upward acceleration event as unnatural, one must perceive these directions of motion in relation to gravity. Five-month-old infants might fail to do this for either of two reasons. First, 5-month-old infants might fail to discriminate between the upward and downward directions of motion. Second, 5-month-old infants might fail to relate each direction of motion on the video screen to the corresponding direction of motion in the world. If 5-month-old infants' perception of the videotaped events was deficient in either of these respects, then neither Experiment 2 nor Experiment 3 would constitute an appropriate test of their sensitivity to the effect of gravity on object motion. Accordingly, in Experiment 4 we investigated whether 5-month-old infants discriminate between videotaped events involving downward versus upward motion and whether they perceive downward motion on the video screen in relation to downward motion in real-world events.

Experiment 4

Five-month-old infants were habituated to a live event in which a ball rolled down an inclined plane with downward acceleration. Then the infants were tested with the videotaped downward and upward acceleration events from Experiment 3. If infants discriminate the two directions of motion, and if they perceive downward motion on the video screen in relation to downward motion in the world, then they should look longer at the videotaped event with upward motion.

In an ideal experiment, baseline preferences between downward and upward motion would be neutralized by habituating separate groups of infants to live events involving downward accelerating motion and upward accelerating motion. It was not possible, however, to create a live event that matched the videotaped event in which the object moved upward with increasing speed. Consequently, all of the infants were habituated to the downward accelerating event. Their test-trial looking preferences were compared to the looking preferences of the infants in Experiment 3, who viewed the same test events after habituation to a videotaped event with constant speed motion in a neutral, horizontal direction. If infants perceive videotaped directions of motion as adults do, then the infants in Experiment 4 should look longer, relative to the infants in Experiment 3, at the test event with upward acceleration.

Method

Subjects. Participants were 3 girls and 5 boys ranging in age from 4 months, 15 days, to 5 months, 15 days (M = 4 months, 26 days). No infant failed to complete the experiment.

Displays and apparatus. The habituation display consisted of a plane inclined 30° downward from left to right, presented against a white background with horizontal stripes (Figure 7). The plane was the same in size and orientation as that in the downward videotaped events; it was positioned just in front of the TV screen. The ball was 6 cm in diameter; it was made of white foam rubber with colored dots and black stripes. On each habituation trial, the ball was released by a hand at the upper end of the plane, it rolled silently down the plane, and it was caught by a second hand at the lower end of the plane. Upon catching the ball, the second hand returned it to the starting place, and the event was repeated. The presenters who manipulated the ball were otherwise out of view. As in the videotaped events, the ball rolled 40 cm at the average speed of 22.2 cm/s. The infant watched the live display from a distance of about 110 cm. At this location, the ball subtended about 3° and moved at about 12°/s.

To familiarize infants with the TV apparatus, each infant was shown one videotaped event before the habituation sequence. That event consisted of the ball rolling on the horizontal plane while steadily speeding up (i.e., the same speeding-up motion to be presented throughout the study, but with rightward acceleration). The test events were the same as those of Experiment 3.

Design and procedure. The design and procedure were the same as in Experiment 3 except as follows. Infants were shown two trials of the videotaped rightward acceleration display prior to habituation. Then they were positioned at a greater distance from the display (to discourage attempts to reach for the object) and were habituated to the live event. The habituation event was produced by two display presenters standing on the two sides of the display, out of view behind the curtain. After the screen was raised, the presenter standing on the left side of the display placed the ball on the left upper side of the surface and released it. The second presenter caught the ball on the right side of the surface and returned it to the first presenter. After habituation, the infant was returned to his or her original position and the videotaped test trials were given, following the procedure of Experiment 3. Interobserver agreement averaged .93.

Results

Mean looking times during the habituation and test trials are presented in Figure 8. The test trial looking times were first analyzed as in Experiment 3. The only significant effect in this analysis was the main effect of test event, $F(1, 6) = 7.62$, $p < .05$: Infants looked longer at the upward event than at the downward event.

A second ANOVA with the additional between-subjects factor of experiment compared the test trial looking patterns in Experiment 4 to those of Experiment 3. This analysis revealed a significant Experiment × Test Event interaction, $F(1, 12) = 9.70$, $p < .01$, complicated by a triple interaction of experiment, test order, and test event, $F(1, 12) = 17.84$, $p < .002$. The infants habituated to live, downward motion (Experiment 4) showed a reliably greater preference for the upward test event than did the infants habituated to videotaped, horizontal motion (Experiment 3). Moreover, the infants in Experiment 4 looked longer at whichever test event was presented first, whereas those in Experiment 3 had looked longer at whichever test event was presented second.

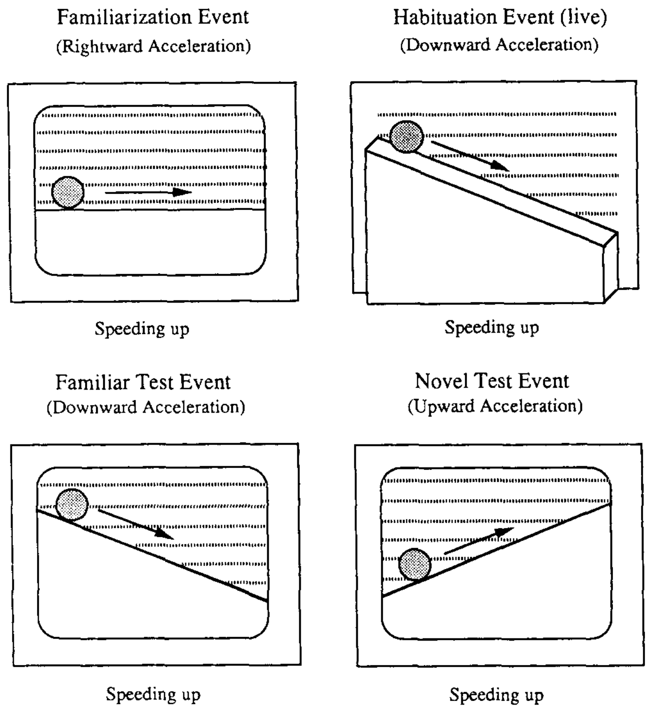

Figure 7. Familiarization, habituation, and test events for Experiment 4.

Discussion

After habituation to a live event in which a ball rolled downward on an inclined plane, 5-month-old infants looked less at a videotaped event in which a ball rolled downward on an inclined plane than at a videotaped event in which a ball

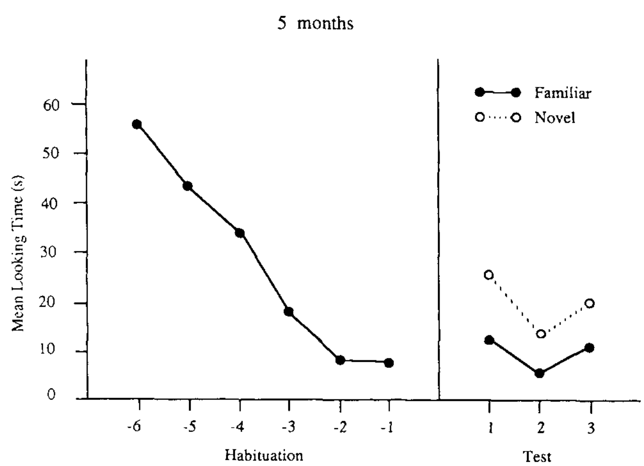

Figure 8. Looking time on the last six habituation trials and the six test trials of Experiment 4.

rolled upward on an inclined plane. Because these test events differed only with respect to the direction of object motion, the two directions evidently were discriminable in the video displays.

The preference for the upward acceleration event was reliably greater in the present experiment than in Experiment 3, in which infants were habituated to a neutral horizontal motion. Because the two experiments presented the same test events, the preference shown in the present study evidently did not reflect either a baseline preference for the upward test event or a reaction to the unnaturalness of that event. We conclude that infants looked longer at the videotaped upward acceleration event because they perceived that event as novel relative to the live event presented for habituation. Experiment 4 provides evidence that 5-month-old infants perceived the directions of object motion in the videotaped events in relation to the direction of object motion in the live event.

Taken together, Experiments 2 and 4 provide evidence that 5-month-old infants perceive both the direction (upward vs. downward) and the motion pattern (speeding up vs. slowing down) of a ball on an inclined plane. Nevertheless, 5-month-old infants do not appear to be sensitive to the naturalness of a moving object's direction and acceleration in relation to gravity.

General Discussion

The present experiments provide evidence that 7-month-old infants are sensitive to certain effects of gravity on the motion of a ball or an inclined plane. In Experiment 1, such infants responded to an object moving downward with increasing speed (or upward with decreasing speed) as more familiar or natural than an object moving downward with decreasing speed (or upward with increasing speed). In Experiment 3, 7-month-old infants responded to a downward accelerating motion as more familiar or natural than an upward accelerating motion.

The findings of Experiments 2, 3, and 4 suggest that sensitivity to these effects of gravity develops between 5 and 7 months of age, at least for the present events. Although 5-month-old infants discriminated between an increasing and a decreasing speed of motion and between an upward and a downward direction of motion, they did not respond to the appropriateness or inappropriateness of a moving object's acceleration or direction of motion. Instead, 5-month-old infants responded consistently to the familiarity or novelty of an object's motion pattern or direction, looking longer at events in which an object's motion changed from speeding up to slowing down or the reverse, and looking longer at events in which an object's direction of motion changed from downward to upward.

Several important issues are not addressed by this research. First, we have no information about the qualitative nature of 7-month-old infants' responses to events inconsistent with gravity. In particular, it is not clear whether such infants regard events in which an object accelerates upward as impossible and therefore surprising, or simply as infrequent and *therefore novel*. Experiments using preferential looking methods cannot address this question directly (see Spelke, Breinlinger, Macomber, & Jacobson, in press, for further discussion).

Certain features of the present findings suggest, nevertheless, that preferential looking patterns did not depend simply on the frequency of events in infants' past experience. First, at neither age did infants exhibit a general preference for upward motion. Because it is likely that infants observe objects rolling downward more often than they observe objects rolling upward, such a preference might have been expected if looking preferences depend primarily on event frequency. Second, sensitivity to gravity appeared to emerge no later in Experiments 1 and 2 than in Experiment 3. Because the test events in Experiment 3 presented objects that moved upward versus downward, whereas those in Experiments 1 and 2 presented objects that moved in the same direction (both downward vs. both upward), one might have expected any response to differences in event frequency to emerge earlier or more strongly in Experiment 3.

A second question concerns the nature of infants' developing sensitivity to effects of gravity. Between 5 and 7 months of age, infants may become sensitive to a highly general constraint on object motion: Unsupported objects accelerate downward. Alternatively, infants and children may develop more local knowledge about how objects move in restricted classes of situations. Between 5 and 7 months, for example, infants may come to appreciate how balls move when they roll on inclined surfaces.

Experiments from several laboratories cast doubt on the view that sensitivity to gravity develops as a whole at about 6 months. Depending on the events presented to infants, sensitivity to effects of gravity has been found to emerge as early as 3½ months (Needham, 1990), as late as 2–3 years (Kim & Spelke, 1991), and at a variety of ages between these extremes (Baillargeon, 1990; Baillargeon & Hanko-Summers, 1990; Keil, 1979; Piaget, 1954; Spelke et al., in press). These findings suggest that sensitivity to gravity develops in a piecemeal fashion.

It is interesting to compare infants' reactions to the present events with infants' reactions to events in which an object falls freely through the air. Spelke et al. (1992) presented infants with events in which an initially stationary object fell freely behind a screen and then was revealed at rest on a platform. After looking times to the outcome of this event had declined to half their initial level, the platform was removed and the test sequence was presented. The object was dropped as before, and the screen was raised to reveal the object either in a new position on the floor of the display (a novel but consistent outcome) or in its former position without visible support (a familiar but inconsistent outcome). Six-month-old infants looked longer at the superficially familiar but inconsistent outcome, in accord with the effect of gravity on object motion. In contrast, 4-month-old infants looked longer at the superficially novel, consistent outcome (Spelke et al., in press).

Additional experiments using nearly the same displays revealed that the younger infants' failure to respond to the effect of gravity could not be attributed to the difficulty of the occluded-object method. First, experiments using fully visible events in which a falling object either landed on a surface or halted abruptly in midair provided evidence for the same change between 4 and 6 months: Only the older infants looked longer at the event inconsistent with gravity (Spelke & Jacobson, 1992). Second, in experiments using the occluded-object method, 4-month-old infants looked longer at a superficially familiar event outcome in which a ball fell behind a screen and reappeared *beneath* the first surface in its path (Spelke et al., in press, Experiment 1). Young infants evidently appreciate that a falling, hidden object will not pass through a surface. They may fail to appreciate, however, that it will continue falling until it arrives at a supporting surface.

The similarity between the ages of the infants in the present experiments and the ages of those in the experiments by Spelke et al. (in press) and Spelke et al. (1992) supports two suggestions. First, perceptions of visible object motions and inferences about hidden object motions may develop in concert in human infancy. In this respect, infants may differ from adults and older children, who appear to be more sensitive to physical constraints on object motion when they perceive moving objects than when they must infer the motions of objects that are not in view (e.g., Kaiser, Proffitt, Whelan, & Hecht, in press; Kim & Spelke, 1991; Shanon, 1976; but see Proffitt & Gilden, 1989). Second, at about 6 months of age, infants may become sensitive to a number of manifestations of the effect of gravity on object motion. This sensitivity might be innate, emerging at a maturationally determined time in infancy, or it might be acquired through specific encounters with objects.

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