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INFANT SENSITIVITY TO SHADOW MOTIONS

Gretchen A. Van de Walle
Rutgers University

Jayne S. Rubenstein
Cornell University

Elizabeth S. Spelke
Massachusetts Institute of Technology

Preferential looking experiments investigated 5- and 8-month-old infants' perception and understanding of the motions of a shadow that appeared to be cast by a ball upon a box. When all the surfaces within the display were stationary, infants looked reliably longer when the shadow moved than when the shadow was stationary, indicating that they detected the shadow and its motion. In further experiments, however, infants' looking was not consistent with a sensitivity to the shadow's natural motion: They looked longer at natural events in which the shadow moved with the ball or remained at rest under the moving box than at unnatural events in which the shadow moved with the box or remained at rest under the moving ball. These findings suggest that infants overextend to shadows a principle that applies to material objects: Objects move together if and only if they are in contact. In a final experiment, infants were habituated to a moving shadow that repeatedly violated one aspect of the contact principle. In a subsequent test they failed to infer that the shadow would violate another aspect of the contact principle. Instead, they appeared to suspend all predictions concerning the behavior of the shadow.

Because environments are made visible by illumination, and because most sources of illumination are directional, shadows are among the most common

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Direct all correspondence to: Gretchen Van de Walle, Department of Psychology, Rutgers University, 101 Warren Street, Newark, NJ 07102 <gretchen@psychology.rutgers.edu>.

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entities in the visual world. Shadows create problems, however, for perceivers who seek to attend to surfaces and objects. Like the edges of a visible object or surface marking, the edges of a shadow are characterized by intensity changes; unlike surfaces and markings, however, shadows are not enduring parts of the layout and have few affordances for action. Effective perception of the surface layout therefore requires that perceivers distinguish intensity changes corresponding to shadows from intensity changes corresponding to objects and surfaces.

Shadows also are problematic for learners who seek to understand the behavior of material objects. Like objects, shadows move. Because shadow motions are a function of the motions of objects and light sources, however, they differ from object motions. Indeed, shadow motions violate all the constraints on the motions of objects to which young perceivers are sensitive (see below). Effective reasoning about the perceptible world therefore requires that perceivers distinguish shadows from material objects and apply different principles in reasoning about them.

The present experiments are an initial attempt to determine whether and how infants solve these problems. For these studies, we created an experimental display in which a shadow could undergo either natural or unnatural motions. Our first experiment indicated that the shadow appeared natural to a group of naive adults, who had appropriate expectations of its motion. Three further studies therefore were conducted with infants, using a preferential looking method. The second experiment provided evidence that infants perceived and attended to the shadow in the display. We therefore asked in the third experiment whether infants confused the shadow with an object or surface marking in their reasoning, falsely applying to the shadow constraints on the behavior of surfaces and objects. Because such overgeneralization evidently occurred, we asked in a final study how infants' expectations about shadow motion are changed by the experience of viewing a shadow that moves repeatedly in violation of constraints on objects.

Shadow Motions and Object Motions

Shadow motions violate three principles that guide young infants' object perception and physical reasoning (Spelke & Van de Walle, 1993). First, young infants represent material objects as moving *continuously*, on paths that are connected (e.g., Baillargeon & Graber, 1987; Spelke, Kestenbaum, Simons, & Wein, 1995; Wilcox, Rosser, & Nadel, 1994; Wynn, 1992; Xu & Carey, 1996) and unobstructed (e.g., Baillargeon & Devos, 1991; Carey, 1997; Sitskoorn & Smitsman, 1995; Spelke, Katz, Purcell, Ehrlich, & Breinlinger, 1994). Shadows violate the continuity principle: When a shadow moves from one surface to another, it jumps between those surfaces tracing no connected path (Figure 1a); when the shadows of two objects move into contact on a single surface, they do not serve as barriers to one anothers' continued motion. Second, young infants represent material objects as moving *cohesively*, maintaining their connectedness and boundaries (e.g., Carey, 1997; Spelke, Breinlinger, Jacobson, & Phillips, 1993). Shadows vio-

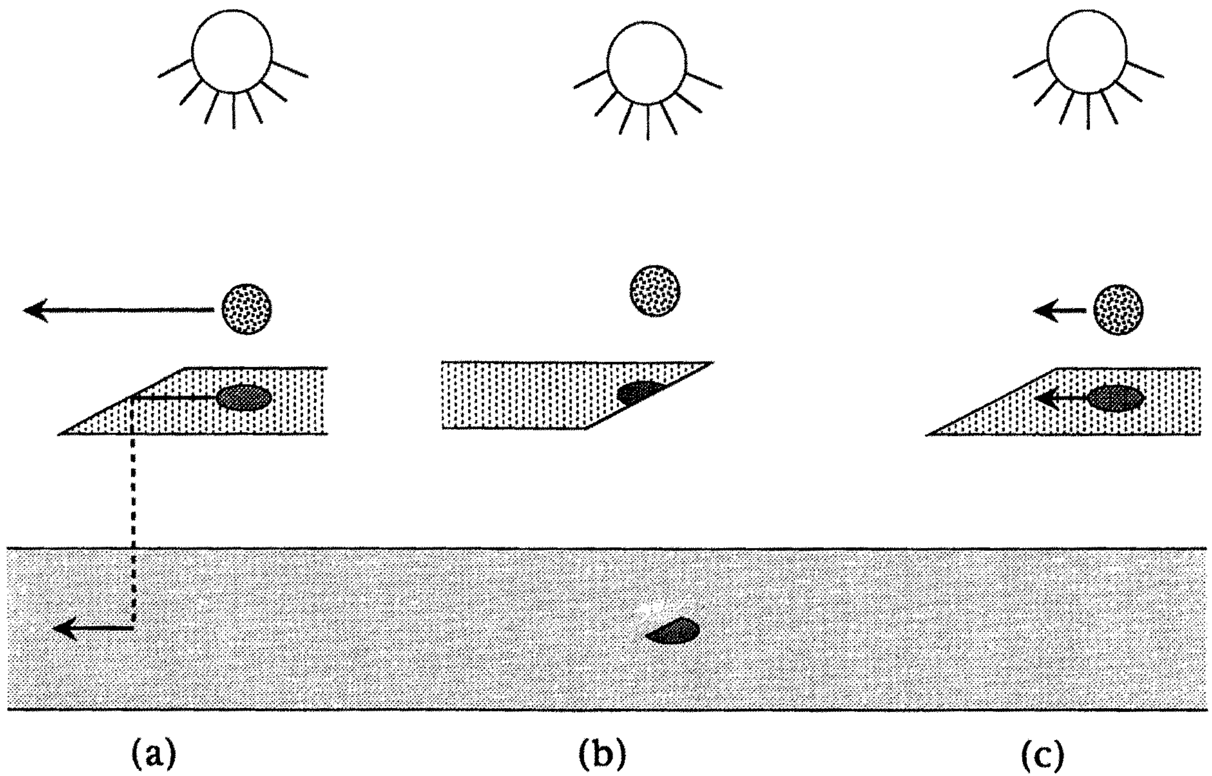


Figure 1. Some natural shadow motions that violate the principles of (a) continuty, (b) cohesion, and (c) contact.

late the cohesion principle by blending together when they move into contact and breaking apart when they move from one surface to another (Figure 1b). Third, young infants endow material objects with the power to influence each others' motion when and only when they come into *contact* (e.g., Ball, 1973; Leslie & Keeble, 1987; Oakes, 1994). Shadows violate the contact principle by moving together with the light source and the object that produce them, even though a shadow is never in contact with its light source and often appears at a distance from its object (Figure 1c).

Infants might cope with these violations of constraints on object motions in any of three different ways. First, infants might possess a filtering mechanism that prevents their perceiving or attending to the motions of shadows. With such a mechanism, children might never notice that shadows violate constraints on object motion and so would not need to learn about those violations. Second, infants might possess a mechanism for distinguishing objects and surface markings from shadows. With such a mechanism, they might gain knowledge about object motions and about shadow motions, applying each body of knowledge only to the appropriate kinds of entities. Third, infants might perceive objects, surface markings, and shadows, and yet apply a single system of knowledge, appropriate to the motions of objects, to all inanimate perceptible entities. With this system of knowledge, infants would successfully predict and interpret the behavior of objects. When they encountered entities such as shadows, however, their predictions and interpretations would be systematically in error.

Children's Reasoning about Shadows, Light, and Nonsolid Substances

Research showing that preschool and school-aged children make systematic errors in reasoning about shadow phenomena provides suggestive support for the third possibility (Carey, 1991; deVries, 1986; Piaget, 1960, 1962; Smith, Carey, & Wiser, 1985). Children often judge that shadows, like objects, exist in the dark (Piaget, 1960), take up space (Carey, 1991; Smith et al., 1985), and move continuously (deVries, 1986). When children are shown that these judgments are incorrect, they appear puzzled but do not shift to correct judgments. Similar errors occur when preschool children reason about the behavior of light and sound (Rosser & Narter, 1995). When children were asked to choose, from a set of alternatives, the correct account of how sound or light travels from a source to a perceiver through different media and in the presence of obstacles, they systematically rejected explanations that violated the continuity principle, and they sometimes accepted incorrect explanations that accorded with constraints on object motion.

Turning to infants, recent research has investigated early developing inferences about a different kind of entity that violates constraints on objects: sand (Huntley-Fenner, Carey, Klatt, & Bromberg, 1995, cited in Carey, 1997). Experiments assessed whether 8-month-old infants reason about sand in accord with the principle of continuity (which applies to sand) and the principle of cohesion (which does not). The investigators first conducted preferential looking experiments involving an entity with the shape, color, and texture of a sand pile but the consistency and behavior of a solid material object. After exploring this object tactually and watching it move in accord with all constraints on object motion, infants were presented with test events in which the object either moved in accord with, or in violation of, the continuity or cohesion principle. Infants looked longer at the events in which the object violated each principle, consonant with the findings of previous studies (e.g., Baillargeon & Devos, 1991; Spelke et al., 1995). Next, the experiments were repeated with a true sandpile, formed by pouring a quantity of sand from a transparent cup. After feeling the sandpile and watching events in which portions of sand were poured, infants viewed the same test events as in the studies with the solid object. Their patterns of preferential looking suggested that the infants correctly inferred that the sand, like the solid object, would not pass through the surface. In contrast, infants did not appear to infer that the sandpile would move non-cohesively, unlike the object. This evidence would seem to indicate that infants did not reason consistently about motions of the sand that violated constraints on the motions of objects.

All these studies provide evidence that children and infants perceive and attend to entities whose behavior violates constraints on objects: If they did not, then they should not have made any consistent inferences about the behavior of shadows, light, or sand. Nevertheless, the participants in these experiments appeared to have no understanding of those aspects of the entities' behavior that violated constraints on objects. Because none of the studies directly investigated infants' perception of, or reasoning about, shadows, however, the present experiments were undertaken. Like Huntley-Fenner et al. (1995), we investigated infants' perception and understanding of shadow motions using paradigms well tested in studies of infants' perception and understanding of objects. Our point of departure is a set of experiments providing evidence that infants apply the contact principle to solid material objects.

Infant Sensitivity to Constraints on Object Motion: The Contact Principle

The contact principle captures two constraints on object motion: no action at a distance (distinct objects move together only if they are in contact) and action on contact (distinct objects move independently only if they are separated). Ball (1973) investigated infants' sensitivity to the former constraint, by presenting infants at various ages with an event in which one object moved behind a screen and then a second object, which initially was stationary and half-occluded by the screen, began to move in the same direction: an event for which adults infer contact between the objects (Michotte, 1963; Van de Walle, Woodward, & Phillips, 1994). After repeated presentation of this event, infants were tested with events in which the first object contacted or stopped short of the second object. Relative to the looking times of infants in a separate baseline condition, infants in the experimental condition looked longer at the no-contact event, both in the sample as a whole and in a subset of the sample including only infants under 7 months of age (Spelke & Van de Walle, 1993). The same looking patterns were obtained in a recent replication of Ball's experiment with 3- and 6-month-old infants (Van de Walle et al., 1994). Because infants tend to look longer at more novel events, these findings provide evidence that infants inferred that the objects touched behind the screen, in accord with the constraint of no action at a distance. More recent experiments using similar logic provide evidence that 5.5-month-old infants also reason about collision events in accord with the complementary constraint of action on contact (Kotovsky, 1992, cited in Kotovsky & Baillargeon, 1994).

A number of experiments provide evidence that the contact principle guides 6- to 8-month-old infants' apprehension of causal relations between visible objects (Baillargeon, 1993; Leslie, 1984; Leslie & Keeble, 1987; Oakes, 1994; but see also Oakes & Cohen, 1990). For example, Oakes (1994) presented 7-month-old infants with a causal event in which two fully visible objects moved in immediate succession and on contact, and with two non-causal events in which a spatial gap or a temporal delay separated the objects' motions. Following habituation to a causal event, infants dishabituated to a non-causal event and vice versa, but infants habituated to one non-causal event remained habituated to the other non-causal event. These findings suggest that the infants perceived the events as causal when, and only when, the objects moved in accord with the contact principle.

Finally, a large number of studies provide evidence that infants perceive the unity and boundaries of objects in accord with the contact principle. When the visible ends of an object move together behind a central occluder, 2- and 4-month-old infants perceive the ends of the object as connected behind the occluder (e.g., Johnson & Aslin, 1995; Kellman & Spelke, 1983; Slater, Morison, Somers, Mattock, Brown, & Taylor, 1990; see Kellman, 1993, for review). When parts of a moving, occluded object are revealed over time, infants again perceive the unity of the object (Van de Walle & Spelke, 1996). When the two ends of an unseen object are grasped by an infant's two hands and are felt to move rigidly together, the two ends are perceived as connected (e.g., Streri & Spelke, 1988). In all these situations, object perception accords with the contact principle (see Spelke & Van de Walle, 1993, for review and discussion).

In light of this research, we investigated infants' reasoning about the motions of shadows. Contrary to the constraint of no action at a distance, a shadow moves jointly with motions of the spatially separated object and light source that cast it; contrary to the constraint of action on contact, a shadow does not move jointly with the surface onto which it is cast. If infants reason appropriately about the behavior of shadows, therefore, they should infer that moving shadows will violate the contact principle in systematic ways. If infants reason about all inanimate perceptible phenomena in accord with the constraints on object motion, in contrast, then two predictions follow. First, infants shown a stationary shadow should overextend principles governing the motions of objects to that shadow, falsely inferring that the shadow will move jointly with the surface on which it is cast and not with the object that casts it. Second, infants shown a moving shadow whose motion violates the contact principle should view the shadow as unpredictable and make no consistent inferences about its behavior.

EXPERIMENT 1

Because the experiments with infants presented visual displays in which a shadow underwent both natural and unnatural motion, the displays all used deceptive light and shading to give the impression that a shadow was produced by one source and object when, in fact, it was produced by a different source and object. Before undertaking the experiments with infants, we investigated whether we had succeeded in creating the impression of a naturally cast shadow for adults. In addition, we investigated whether adults, who watched our displays with no specific instructions and no prior mention of the shadow, would respond appropriately to the natural and unnatural shadow motions.

Method

Participants. Participants were 23 students or employees of Cornell University (14 males and 9 females) ranging in age from 16 to 42 years ($M = 22$ years). Participants were unaware of the purpose of this study or of our research with infants.

Displays. The display for Experiment 1 consisted of a puppet stage containing a suspended object, a box below the object on the stage floor, and a shadow cast upon the box (see Figure 2). The stage contained a white painted wood floor (121.9 cm wide, 76.2 cm deep) and gray foamcore walls (94.0 cm tall) on the back and sides. In front of the stage was a white painted wooden panel with an opening (71.1 cm wide, 50.8 cm tall) through which infants viewed the displays. A white cloth screen was lowered over this opening to conceal the display between trials. The object was a gray styrofoam 10.2 cm diameter sphere, suspended by a horizontal gray metal 0.64 cm diameter bar from the stage sides approximately 40.6 cm above the stage floor. The box (15.2 cm tall, 45.7 long, 30.5 cm deep) stood at the center of the stage floor directly below the object. The sides of this box were white painted wood, and its top was made of frosted glass covered underneath by semi-opaque white plastic. The top of the box was designed to appear to have the same opaque surface as its sides.

The shadow on the surface of the box was created by a cardboard disk below the top of the box and lit by two 5-watt night-lights within the box. This disk was held in place by a vertical rod, 0.64 cm in diameter, which extended through the box and beneath the stage through a hole in the stage floor. This vertical rod was attached beneath the stage to a horizontal metal bar which extended through both sides of the display stage. Both this rod and the rod holding the ball could be attached to a vertical plexiglas pole using metal screws. Light and shading in the

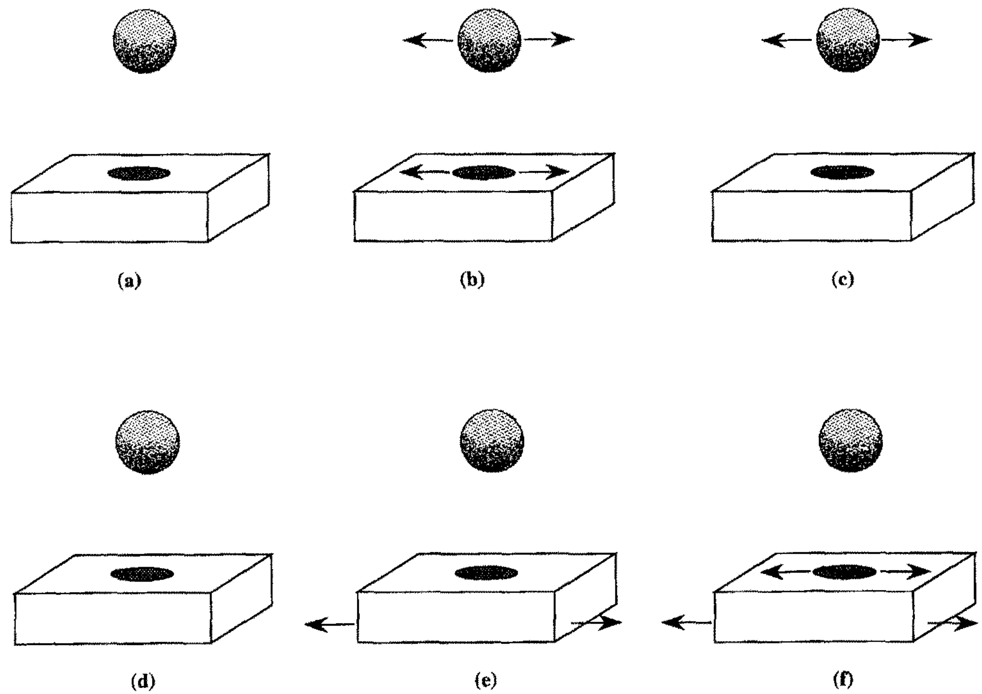


Figure 2. Schematic depiction of the displays used in Experiments 1, 3, and 4. Arrows indicate the direction and extent of motion of the ball, box, or shadow. Infants in Experiment 3A and Experiment 4A were tested with the events depicted in 2b and 2c, following habituation with 2a (Exp. 3A) or 2e (Exp. 4A). Infants in Experiment 3B and Experiment 4B were tested with the events depicted in 2e and 2f, following habituation with 2d (Exp. 3B) or 2b (Exp. 4B).

display was arranged so that the entire array would appear to be illuminated from above by a hidden light source, all the visible surfaces would appear to be gray and opaque, and the shadow would appear to be cast by the suspended ball. To accomplish this, the overhead lights in the room were dimmed, and the main source of light in the stage came from a 100-watt bulb set at approximately 1/3 intensity, positioned on the ceiling of the stage pointing directly down at the ball. The nightlights inside the box were just intense enough to block the visibility of the natural shadow of the suspended ball on the surface of the box. The ball was shaded with black paint on its underside, in order to create the impression that it was lit solely from above. Light-meter measurements taken at the center of the ball, the visible area surrounding the ball (i.e., the back wall of the stage), the shadow, and the visible area surrounding the shadow (i.e., the top of the box) yielded readings of 8.56 cd/m^2, 13.02 cd/m^2, 17.73 cd/m^2, and 29.12 cd/m^2, respectively. The contrast ratio at the edges of the ball therefore was 1.5, and the contrast ratio at the edges of the shadow was 1.7, with the ball and the shadow each darker than their surroundings.

This display could be presented without motion (Figure 2a), or it could move in two ways. First, the display could undergo natural motion of the ball and shadow (Figure 2b). To create this motion, both the rod holding the ball and the rod holding the disc that produced the shadow were attached to a vertical plexiglas pole at one side of the display by means of metal screws. The experimenter moved the pole back and forth continuously throughout the event for a total distance of 10.2 cm at a rate of approximately 25 cycles per minute. Second, the display could undergo motion of the ball while the shadow unnaturally remained at rest (Figure 2c). To produce this motion, only the rod suspending the ball was attached to the plexiglas pole, which was moved in the same manner.

This apparatus was modified to present three further displays in which the box and shadow were stationary (Figure 2d), the box moved independently of the shadow (Figure 2e), or the box and shadow moved together (Figure 2f). A horizontal metal rod, identical to the rod that supported the suspended ball, ran through the sides of the box and through the side walls of the display. At one end, the rod could be attached to the plexiglas pole by metal screws. Small wheels were placed inside the box, out of sight, so that the box could roll silently on the stage floor (to an adult observer, the wheels were not visible and the box appeared to slide).

For the display in which only the box moved, the rod holding the box was attached to the plexiglas pole. For the display in which the box and shadow moved together, both the rod holding the box and the rod holding the disc that produced the shadow inside the box were attached to the plexiglas pole. Both motions were produced by the experimenter at the same rate and in the same manner as for the displays with the moving ball. In order to mask any incidental and unintended noises produced by these motions, a tape recording of white noise was played throughout the experiment.

Design. The 10 adults in Condition A were presented with the displays in Figure 2a-2c, and the 13 adults in Condition B were presented with the displays in Figure 2d-2f. Each participant first saw a stationary display, followed by the two moving displays. Approximately half the participants in each condition saw the display with natural shadow motion before the display with unnatural shadow motion.

Procedure. Prior to seeing the displays, participants were told that they would view three displays from studies with infants and would be asked for their impressions of the displays. The shadow was not mentioned. Participants were asked to rate the "naturalness" or "unnaturalness" of each display on a scale from 1 (most natural) to 5, and to comment on the criteria they used for their ratings.

Participants were seated in a chair in front of the display at the same eye level as that of the infants. The experimenter then raised the screen to reveal, in turn, the stationary display and the motion displays. A participant was allowed as much time as he or she needed to make a rating for each display, and then the screen was lowered. Questions were deferred until the end of presentation of the three displays, at which time the experimenter asked the participant to explain his or her ratings and provided an explanation for the study.

Results

Table 1 presents the mean ratings for each of the displays. Adults tended to rate the stationary display, the event in which the ball and shadow moved together, and the event in which the box moved alone as relatively natural. In contrast, they tended to rate the event in which the ball moved alone and the event in which the box and shadow moved together as unnatural. A 2 (condition) x 3 (event) analysis of variance (ANOVA) with event as a within subjects factor revealed that the events with natural shadow motion were rated as more natural than the events with unnatural shadow motion, $F(2, 42) = 18.9$, $p < .001$. Paired t-tests comparing the two events with motion in each condition revealed that the event with natural shadow motion was rated as more natural than the event with unnatural shadow motion, both for the participants who viewed events in which the ball moved, $t(9) = 3.58$, $p < .01$, and for the participants who viewed events in which the box moved, $t(12) = 3.12$, $p < .01$.

Table 1. Adults' Mean Ratings of the Naturalness of the Shadow Motion Displays

Condition	Stationary	Natural for shadows	Unnatural for shadows
A	2.70[a] (0.42)[b]	2.40 (0.43)	4.50 (0.31)
B	2.53 (0.37)	3.38 (0.35)	4.62 (0.14)

Notes. Maximum score for unnaturalness = 5.
[a]mean
[b]standard error

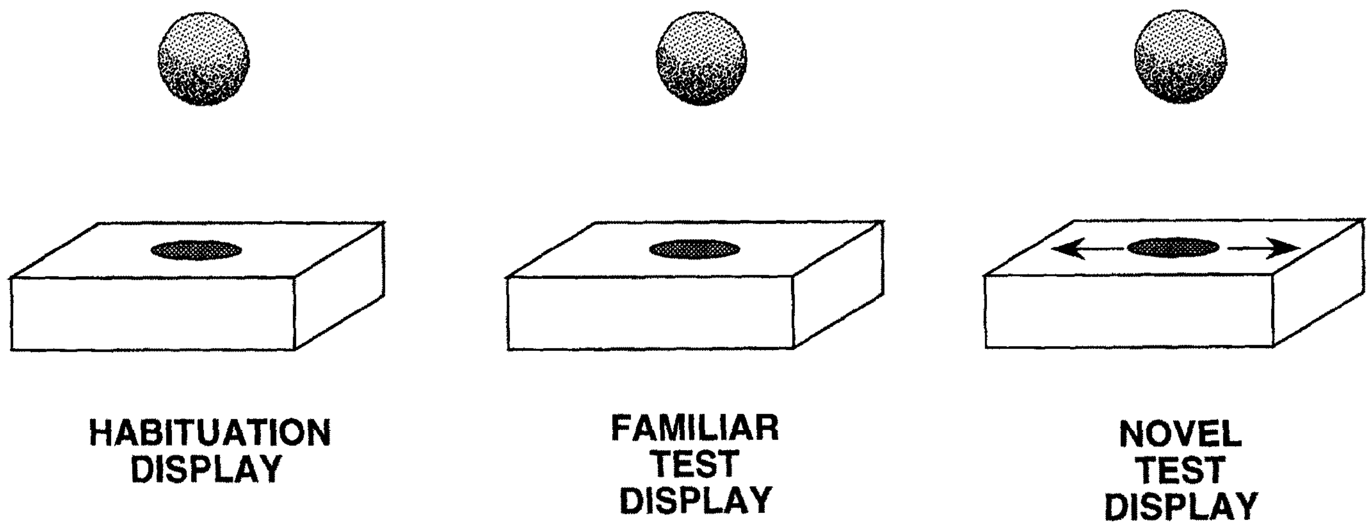


Figure 3. Schematic depiction of the displays used in Experiment 2.

The verbal comments of the participants suggest that they perceived the shadow as cast by the ball. Most participants did not comment on the shadow at all until they saw the event in which the shadow moved unnaturally. Until that time, participants tended to comment only on the ball (whose mode of suspension by the metal rods was sometimes described as unnatural) and the box.

Discussion

The findings of this experiment provide evidence that adults detected the shadow motion and responded as intended to its naturalness. The event in which the ball and shadow moved together was rated as substantially more natural than the event in which the ball moved alone. Similarly, the event in which the box moved independently was rated as more natural than the event in which the box and shadow moved together. Because only the motion of the shadow distinguished these pairs of displays, the ratings indicate that adults detected the shadow and its motion, that they perceived the shadow as cast by the ball, and that they expected the ball and shadow to move together. Participants' verbal comments supported these conclusions, suggesting that the shadow was registered but did not draw participants' attention until it moved unnaturally. The remaining experiments therefore investigated infants' perception of these displays.

EXPERIMENT 2

This experiment investigated whether 5- and 8-month-old infants perceive and attend to the shadow in the present display. Infants first were familiarized with a stationary display very similar to that of Experiment 1. Then infants were tested with two displays that were identical except for the motion of the shadow: the stationary display seen during habituation and a display in which only the shadow moved (Figure 3). If infants failed to perceive or attend to the shadow, the difference between these test displays should not have been detectable, and infants should have shown no consistent looking preferences between them. If infants detected the shadow, in contrast, then they might be expected to look longer at the display in which the shadow moved, for three reasons. First, the latter display involved motion, and infants tend to look longer at moving than at stationary displays (e.g., Kellman, 1993). Second, the latter display involved a change from the habituation display, and infants tend to look longer at displays that are novel (e.g., Bornstein, 1985). Third, the latter display involved an unnatural motion, and infants tend to look longer at events that are unnatural and unexpected (e.g., Baillargeon, 1993, 1995).

Method

Participants. Participants were six 5-month-old infants (range, 4 months, 21 days to 5 months, 26 days) and six 8-month-old infants (range, 7 months, 20 days to 8 months, 11 days) from the Ithaca, NY area. Five infants (2 at 5 months) were female and 7 were male. All the infants were born of full-term pregnancies and had no known abnormalities. Three additional infants were eliminated from the experiment because of fussiness (1) or experimenter error (2).

Apparatus and Displays. The apparatus was the same as that of Experiment 1, except for the mechanism used to support the ball (monofilament wires instead of metal rods) and the mechanism used to create and move the shadow (an opaque plastic disc instead of cardboard, moved by direct manipulation by an experimenter seated beneath the stage). There was no noticeable difference in the appearance of the shadow in Experiments 1 and 2. Two displays were presented to infants: a completely stationary display and a display in which the shadow moved while the ball and box remained at rest. In the latter display, the motion of the shadow was the same in extent and speed as in Experiment 1.

Infants viewed the display from a semi-reclining seat (5-month-old participants), booster seat (8-month-old participants), or parent's lap (participants at either age who became fussy in the original seat). If the infant sat on a parent's lap, the parent was instructed to close her eyes during the test trials. The infant's head was centered approximately 46.0 cm in front of the stage opening, with his or her eye level between that of the ball and that of the shadow. One or two observers viewed the infant's eyes through small holes cut in the back wall of the stage. The display was not visible from the observers' position.

Design. All the infants were familiarized with the stationary display and tested with both the stationary display and the display with shadow motion on six alternating trials. Half the participants at each age viewed the stationary display first during the test series.

Procedure. At the start of the study, the infant was placed in the seat facing the apparatus with the front curtain closed, and then the curtain was raised to reveal the stationary display. Looking time at the display was measured by observers using button boxes linked to a microcomputer. In addition, a video camera positioned to the right of the display recorded the infant's looking during the study and served to check on the accuracy of looking times and on the possibility of observer bias effects (see below).

After the screen was raised, each trial began with the infant's first look at the ball, the shadow, or the box, and it continued as long as the infant looked somewhere in the display stage, excluding the observer holes. A trial ended when the infant was judged to have looked away for 2 s continuously or to have looked for a total of 120 s. The end of the trial was signaled by a soft beep from the computer and was followed by the lowering of the screen.

Habituation trials with the stationary display continued until 14 trials were presented or until a criterion decrement in looking time occurred: total looking time on 3 consecutive trials that was less than half the sum of the looking times on the first 3 habituation trials whose total duration exceeded 12 s. After the last habituation trial, on signal from the microprocessor, each infant was shown the stationary display and the display with shadow motion on 6 alternating trials, following the same procedure as for habituation. On trials with shadow motion, the motion began before the screen was raised and occurred continuously until the screen was lowered. Interobserver agreement, calculated for a total of 50 participants across the present series of experiments, averaged 93%.

Procedures to Test for Observer Bias. Although observers were uninformed of the order of test displays for a given infant and viewed the infant from positions at which the displays were not visible, it has recently been suggested that these safeguards against observer bias are inadequate (Fernald & McRoberts, 1996). Initially blind observers may gain information about the order of test displays through subtle noises in the room or actions by the baby or presenter. If such information is detected unconsciously, observers' coding may be responsive to biasing information of which they are unaware.

To test for possible unconscious bias on the part of the primary observer, videotapes of infants in this experiment were recoded by three trained observers who had no knowledge of the present studies and had never seen the present displays. These codings were performed for the test trials only, for every infant whose video record was sufficiently clear that all 6 test trials were judged codable by the new observers: A total of 5 infants (30 trials) were so coded. Each video observer worked with a second experimenter, also naive to the purpose and displays of the original study, who listened to the experiment over earphones and cued the videotape to the start of each test sequence. The video observer coded infants' looking times without access to the video soundtrack, following the instructions that had been given to the live observers and pressing a button connected to the microprocessor as in the original experiment. For each test trial, the second experimenter compared the timing of the computer beep that was audible on the soundtrack of the videotape (signaling the point in time at which the live observer's coding had served to end a trial) to the computer beep generated by the video coder. This experimenter thereby judged, for each trial, whether the live observer had ended the trial before, after, or at the same time (with no perceptible difference) as the video observer. The video coder's looking time data were compared to the data generated by the original live observer separately for each trial type (stationary vs. moving), as were the number of trials when the live observer was judged to end the trial earlier vs. later than the video observer.

Comparisons of the looking time data scored by the original and the video observers indicated that the video observers recorded, on average, looking times that were .6 s longer than the live observers on the stationary test trials and .84 s longer than the live observers on the moving test trials: a nonsignificant difference $t(14) = -0.07$. On 15 of the 30 test trials coded both live and on video, there was no detectable difference between the trial endings signaled by the live and video observers. The live observer ended trials later than the video observer on 6 of the

8 remaining stationary trials and on 3 of the 7 remaining moving trials. The number of trials with a disagreement between the observers reduces to 7 if disagreements smaller than .5 s are disregarded. Both the looking time comparison and the trial ending comparison produced trends that are opposite in direction to that expected if the live observer were biased to record longer looking times for the novel, moving display.

Analyses. Because the looking times during test were highly positively skewed across all the present experiments,[1] trial-by-trial looking times were log-transformed for all the analyses. For the habituation sequence, t-tests compared the looking patterns of 5- and 8-month-old infants on four measures: number of habituation trials, total looking time on the first three trials, total looking time on the last three trials, and total looking time over the entire habituation period. To evaluate dishabituation to each of the test stimuli, t-tests compared the average of the last three habituation trials with the average of the 3 familiar trials and the average of the 3 novel trials.[2] To correct for the possibility of Type I error, a Bonferroni correction was applied to all t-tests conducted on the same data. Because infants were habituated to a criterion, it is possible that some dishabituation occurred from spontaneous recovery of looking. To address this issue as well as to investigate possible interactions, the test data were further analyzed by a 2 (age) x 3 (trial pair) x 2 (test event) ANOVA with the last two factors within subjects. In addition, because looking time data may fail to meet the assumptions of parametric analyses (notably, the assumption of homogeneity of covariance), a Wilcoxon Signed Ranks test also compared the total looking times at the two test displays (Siegel & Castellan, 1988).

Results

Table 2 and Figure 4 present the principal findings of this experiment. On the habituation trials, 5-month-old infants tended to look longer than 8-month-old infants on the first three trials and overall, but no age differences were significant on any measure of looking during the habituation period, all ts < 1. On the test trials, infants dishabituated to the novel display with shadow motion, $t(11) = 6.10, p < .001$, but not to the familiar, stationary display, $t(11) < 1$. The ANOVA fully corroborated these results. Both the 5- and the 8-month-old infants looked longer at the novel display than at the familiar display. Indeed, every participant in the experiment looked longer at the moving display than at the stationary display. The difference in looking times to the two test events was the only significant effect in the ANOVA, $F(1, 10) = 29.9, p < .001$, and it was significant in the non-parametric analysis, Wilcoxon $T = 0, p < .001$.

[1] Mean skewness values (and standard deviations) were 1.72 (.83), 2.61 (1.47), and 1.80, (.5) for Experiments 2, 3, and 4, respectively.

[2] Tests of dishabituation also were conducted comparing the average looking time on the last 3 habituation trials with the first familiar and first novel test trial. The results are the same.

Table 2. Infants' Looking Patterns During Habituation Trials in Experiment 2

Habituation measure	5 months	8 months
Log looking time (s), first 3 trials	5.43[a] (1.26)[b]	4.44 (1.04)
Log looking time (s), last 3 trials	2.37 (0.80)	3.20 (0.58)
Log looking time (s) total	16.47 (2.34)	15.90 (2.28)
Trials (no.)	11.33 (1.38)	11.33 (1.20)

Notes. [a]mean
[b]standard error

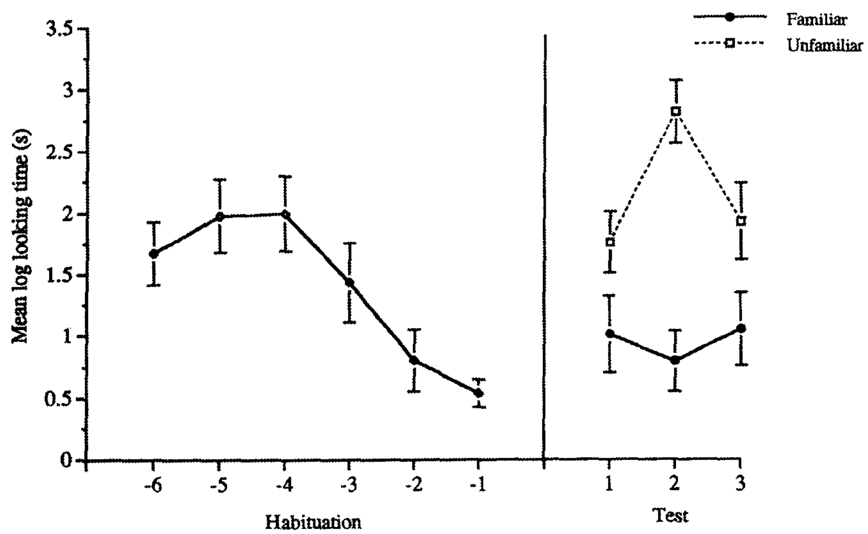


Figure 4. Mean log looking times on the last 6 habituation trials and on the 6 test trials of Experiment 2.

Discussion

After habituation with a fully stationary display that to adults appeared to consist of two objects and a shadow, infants looked longer at a display in which the shadow moved than at the familiar, stationary display. Because only the motion of the shadow distinguished these two displays, this preference provides evidence that the infants detected the moving shadow and attended to its motion.

The findings of this experiment rule out extreme forms of the view that infants fail to perceive or attend to shadows. Because adults evidently perceived the shadow as natural until they viewed the display with unnatural motion, we may suppose that the shadow was no more prominent or attractive than are shadows in some of the natural displays that infants encounter. In view of infants' detection of the present shadow, therefore, it is likely that infants also detect shadows in some natural scenes.

Nevertheless, weaker versions of a perceptual filtering hypothesis are consistent with the present findings. It is possible that infants only detect and attend to shadows that move and/or shadows of high contrast; infants may be less sensitive to shadows than to objects or surface markings. Although infants evidently detect and attend to some shadows in natural environments, we can say little about the strength or generality of this phenomenon. Moreover, these findings demonstrate that infants detected the shadow in this display, but they do not tell us whether infants recognized the shadow as a shadow. Recognition of shadows as such requires an appreciation of the relation between the light source, the ball, and the surface onto which the shadow is cast. Thus, it is possible that infants detected the shadow, but interpreted it as an object or a marking on the surface of the box.

Given that infants detected the shadow in this display, Experiment 3 used the display from Experiment 1 to explore infants' sensitivity to shadow motions. It investigated whether infants appreciate that shadows move with the objects that cast them and not with the surfaces on which they are cast, in violation of the contact principle.

EXPERIMENT 3

Five- and 8-month-old infants were familiarized and tested with the displays presented to the adults in Experiment 1 (see Figure 2). First infants were familiarized with a fully stationary display in which a ball appeared to cast a shadow on a box. Habituation trials were presented until a criterion decrement in looking time occurred, as in Experiment 2, so as to give the infants in Experiment 3 the same opportunity to explore the display and perceive the shadow. After this habituation, separate groups of infants viewed displays in which either the ball or the box moved. In one condition (3A), the ball moved and the shadow either moved with it (a natural event that violates the constraint of no action at a distance) or remained at rest (an unnatural event in accord with that constraint). Figure 2a-2c depicts the habituation and test displays for infants in condition 3A. In the other condition (3B), the box moved and the shadow either remained at rest (a natural event that violates the constraint of action on contact) or moved with it (an unnatural event in accord with that constraint). Figure 2d-2f depicts the habituation and test displays for infants in condition 3B. Looking preferences to the moving test displays were compared, on the assumption that infants would look longer at whichever display appeared more novel or unnatural. If infants are sensitive to the natural motions of shadows, therefore, the participants in this study should have looked longer at the displays in which the shadow's motion was unnatural. In contrast, if infants overgeneralize the contact principle to shadows, they should have looked longer at the display in which the shadow moved naturally, in violation of that principle.

Method

Participants. Participants were 32 infants (16 males, 16 females). Half the infants were 5 months old (range, 4 months, 14 days to 5 months, 15 days) and half were 8 months old (range, 7 months, 18 days to 8 months, 15 days). Five additional participants were eliminated from the study because of fussiness (3) or experimenter error (2).

Apparatus and Displays. The apparatus and displays were the same as those of Experiment 1 (see Figure 2).

Design. Half the infants at each age participated in each of two conditions. Those in Condition 3A were familiarized with the stationary display and then were tested with displays in which the ball moved and the shadow either moved conjointly with it (natural) or remained at rest (unnatural). Those in Condition 3B were familiarized with the stationary display and then were tested with displays in which the box moved and the shadow either remained at rest (natural) or moved with it (unnatural). Equal numbers of male and female infants participated in each condition at each age. The two motion displays were presented on 6 alternating trials, their order counterbalanced across infants within each condition and age group.

Procedure and Analyses. The procedure was the same as in Experiment 2. New pairs of observers scored the videotaped test trials for the 21 infants whose videotaped data were judged scorable on all 6 test trials. As in Experiment 2, all trial-by-trial looking times were log-transformed for all parametric analyses. The habituation measures were calculated as in Experiment 2, and a 2 (age) x 2 (condition: A vs. B) ANOVA compared the looking patterns at the two ages and in the two conditions on each habituation measure. Dishabituation measures were calculated and evaluated as in Experiment 2 for infants in each condition. For the test trials, looking times were subjected to a 2 (age) x 2 (condition: A vs. B) x 3 (trial pair) x 2 (test event) ANOVA with the last two factors within subjects. The non-parametric analyses were as in Experiment 2.

Comparisons of the looking times coded by the live and video observers revealed that the live observer recorded an average of 4.3 s longer looking time at the event that was consistent with the contact principle and an average of 3.0 s longer looking time at the event that was inconsistent with the contact principle $t(62) = -0.21$. Sixty-three of the 126 trials were ended simultaneously by the live and video observers. The live observer ended trials later than the video observer for 19 of the 35 trials in which the shadow motion was consistent with the contact principle and for 15 of the 28 trials in which the shadow motion was inconsistent

Table 3. Infants' Looking Patterns During Habituation Trials in Experiment 3

	5 months		8 months	
	Cond. A	Cond. B	Cond. A	Cond. B
Log looking time (s), first 3 trials	4.15[a] (0.89)[b]	3.44 (0.59)	3.65 (0.69)	3.40 (0.67)
Log looking time (s), last 3 trials	1.84 (0.57)	2.43 (0.36)	2.66 (0.53)	2.02 (0.33)
Log looking time (s) total	10.98 (1.40)	9.52 (1.21)	12.44 (1.69)	10.78 (1.38)
Trials (no.)	11.37 (1.61)	9.37 (1.38)	11.00 (1.16)	11.25 (1.00)

Notes. [a]mean
[b]standard error

with the contact principle. These small, nonsignificant differences provide no evidence for biased observation in Experiment 2.

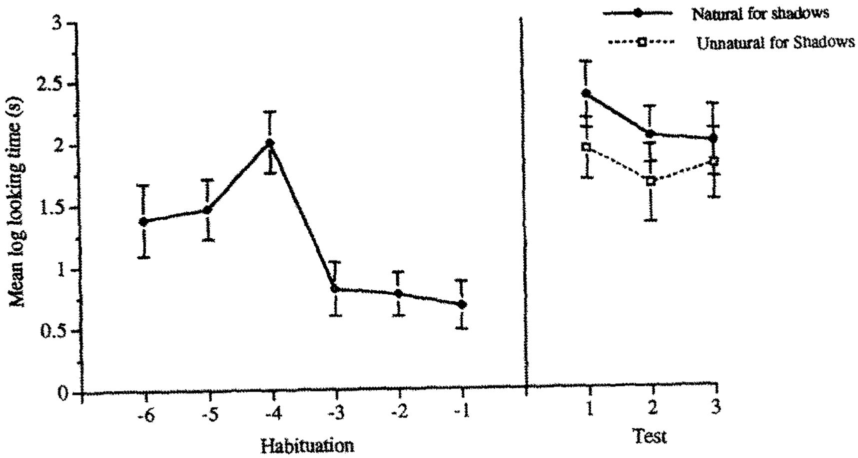
Results

The principal findings are presented in Table 3 and Figure 5. During the habituation period, the ANOVA revealed that infants in Condition A showed marginally longer total looking during habituation than infants in Condition B, $F(1, 28) = 3.30$, $p < .10$. No other reliable effects of age or condition were found for any of the remaining habituation measures.

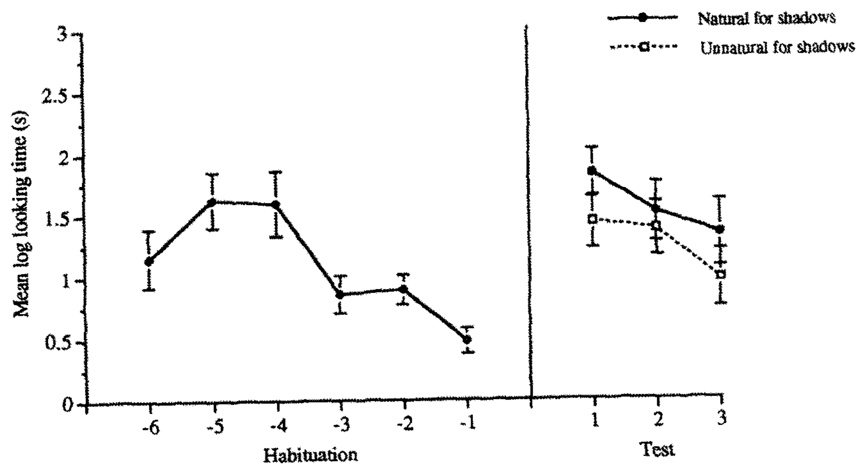
The t-tests revealed that infants' looking during the test period increased to both test displays from the last habituation trials, all $ts < -2.93$, $p < .01$.[3] This finding very likely reflects the fact that both test displays moved whereas the habituation display was stationary. The ANOVA revealed, however, that the infants in both conditions showed a significant preference for the test events that appeared natural to adults, in which the shadow either moved with the ball or remained stationary on the moving box. The ANOVA revealed a main effect of condition, $F(1, 28) = 6.2$, $p < .02$, and test event, $F(1, 28) = 9.58$, $p < .005$. Infants showed longer looking overall in Condition A, and infants in both conditions looked longer at the display with natural shadow motion (Figure 5). There were no other significant effects or interactions.

The tendency to look longer at the event with natural shadow motion was observed at both ages and for both conditions. Separate nonparametric analysis of Condition 3A revealed a significant preference for the event in which the shadow moved with the moving ball over the event in which the ball moved and the shadow remained at rest, Wilcoxon $T = 27$, $p < .05$, two-tailed. Separate analysis of Condition 3B revealed a marginally significant preference for the event in which the shadow remained stationary on the moving box over the event in which

[3]The same results are obtained in tests comparing the average looking time on the last 3 habituation trials with the first natural and first unnatural test trial.



(a)



(b)

Figure 5. Mean log looking times on the last 6 habituation trials and on the 6 test trials of Experiment 3 for infants tested with motion of the ball (Condition 3A, top) and motion of the box (Condition 3B, bottom).

the shadow and box moved together, Wilcoxon $T = 33$, $p < .10$, two-tailed. At 5 months, 13 infants looked longer at the event with natural shadow motion and 3 showed the reverse preference; at 8 months, 12 infants looked longer at the natural event and 4 showed the reverse preference.

Discussion

Infants in this experiment increased looking from the last 3 habituation trials to both test displays. However, given that infants were habituated to a stationary display and tested with moving displays, it is quite likely that infants were responding at least in part to the novelty of the motion. Further, infants who viewed test events involving ball motion (Condition A) showed longer looking during test than infants who viewed motion of the box (Condition B). This might reflect an intrinsic preference for events in which the ball moves or differential dishabituation to such events; Experiment 4 sheds further light on these possibilities. Most importantly, comparison of infants' preferences between the two test displays reveal that infants in both conditions showed a significant preference for the display that was natural for shadows but violated the contact principle. This pattern of preferences provides no evidence that infants are sensitive to distinctions between the motions of shadows and objects. Instead, infants appeared to perceive a natural motion of a shadow as more novel than an unnatural shadow motion, when the former motion violated the contact principle. This looking preference suggests that infants overgeneralized to the shadow a constraint that applies to the motions of material objects.

Because the pair of test displays shown to a given infant differed only with respect to the motion of the shadow, the significant preferences observed in Experiment 3 provide further evidence that moving shadows are detectable by infants. Unlike Experiment 2, however, infants' preferences in Experiment 3 cannot be attributed to a general preference for displays with a greater amount of stimulus motion. In Condition 3A, infants looked longer at the event in which the shadow moved than at the event in which it was stationary. In Condition 3B, in contrast, infants showed the reverse preference. These findings suggest that infants' preferences depended on the perceived objects and motions in the display, not on the quantity of stimulus motion or displacement.

More specifically, two interpretations for the present preference may be offered. First, infants may have perceived the shadow in Experiment 3 as a distinct object. Like the infants in studies by Ball (1973), Kotovsky and Baillargeon (1994), and others, infants may have looked longer at the events with natural shadow motion because the shadow appeared to move with a distant object or to remain at rest relative to a proximal one. These motions are unnatural for objects, because they fail to accord with the contact principle. Second, infants may have perceived the shadow in Experiment 3 as part of the box on which it was cast. Like the infants in studies by Kellman and Spelke (1983), Streri and Spelke (1988), and others, infants may have looked longer at the events with natural shadow motion because this motion appeared to break the shadow and box apart (see also Spelke, Breinlinger, Jacobson & Macomber, 1993; Xu & Carey, 1994). These perceptions also follow from the contact principle (see Spelke & Van de Walle, 1993). On either interpretation, therefore, infants' perception and representation of shadows testifies to a generalization of the contact principle from objects to shadows.

This overgeneralization might be explained in two different ways. First, infants may have correct and contrasting expectations about the behavior of objects and shadows, but they may miscategorize stationary shadows as surface markings or objects. Perhaps the characteristic motion of a shadow—its violation of constraints on the motions of objects or surface markings—enables infants to perceptually identify a shadow as such and allows them subsequently to reason about it appropriately. This view is akin to one theory of infants' perception of animate objects: Infants may categorize a person or animal as animate by detecting aspects of its motion that violate constraints on inanimate objects (Premack, 1990; see also Gelman, 1991; Mandler, 1992). Alternatively, infants may have no expectations about the behavior of shadows, and so their reasoning about shadows may be subject to the same limits as their reasoning about nonsolid substances (Huntley-Fenner et al., 1995, cited in Carey, 1997). If an entity that looks like a shadow or a nonsolid substance moved in accord with constraints on objects, infants would reason about it as if it were an object; if it violated constraints on objects, infants would show no consistent reasoning about its behavior.

These two views can be distinguished by presenting infants with a shadow whose motion violates one constraint on objects, and then testing whether infants now expect the shadow to violate other constraints on object motion. If infants have appropriate knowledge of shadow motions but must see such motions in order to categorize a perceptible entity as a shadow, then infants who view a shadow violating one constraint on object motion should correctly predict how the shadow will move in relation to other constraints on objects. In contrast, if infants have no knowledge of shadow motions, then infants who view a shadow violating one constraint on object motion might show no systematic reactions to further events in which the shadow moves. The last experiment tested these contrasting predictions.

EXPERIMENT 4

The experiment consisted of two conditions, both presenting the same displays and motions as Experiments 1 and 3. In one condition (4A), infants were familiarized with the event in which the shadow behaved naturally in violation of the constraint of action on contact: It remained at rest below the ball during motion of the box on which it was cast (Figure 2e). In the other condition (4B), infants were familiarized with the event in which the shadow moved naturally in violation of the constraint of no action at a distance: It moved conjointly with the ball on the stationary box (Figure 2b). After this habituation sequence, each infant viewed two new events in which the shadow's motion was either natural (and in violation of the contact principle) or unnatural (and in accord with that principle). For the infants in condition 4A, these were the two events of Experiment 3A, in which the ball moved and the shadow's behavior either violated or accorded with the constraint of no action at a distance (Figures 2b and 2c). For the infants in Experiment 4B, these were the two events of Experiment 3B, in which the box moved and the shadow's behavior either violated or accorded with the constraint of action on contact (Figures 2e and 2f).

Method

Participants. Participants were 32 infants. Seventeen males and 15 females were observed, half at 5 months (range, 4 months, 15 days to 5 months, 14 days) and half at 8 months (range, 7 months, 15 days to 8 months, 14 days). Five additional participants were eliminated from the sample because of experimenter error (4) and crying (1).

Apparatus and Displays. The displays were the same as the test displays for Experiments 1 and 3. The apparatus was the same as in Experiment 1, except that no videocamera was present due to technical limitations in the laboratory.

Design. Half the participants at each age were familiarized with the motion of the box and stationary shadow (the action on contact violation) and were tested with the motion of the suspended object with and without conjoint motions of the shadow (respectively, the natural and unnatural events). The remaining participants were familiarized with the conjoint motion of the suspended object and shadow (the no action at a distance violation) and were tested with the motion of the box with and without conjoint motion of the shadow (respectively, the unnatural and natural events). The order of test displays was counterbalanced within each age and condition.

Procedure. This was the same as in Experiment 3, except as follows. During habituation, either the rods attached to the ball and shadow were attached to the plexiglas pole to produce conjoint motion of the ball and shadow, or the rod attached to the box was attached to the pole to produce solitary motion of the box. Between habituation and test, all the rod attachments were altered so as to produce two new patterns of motion, again with attachments as in Experiment 3.

Analyses. As in Experiments 2 and 3, the trial-by-trial data were log-transformed for all parametric analyses. For the habituation period, the looking time data were analyzed as in Experiment 2. In addition, the habituation data of Experiments 3 and 4 were compared by a 2 (experiment) x 2 (age) x 2 (condition: A vs. B) ANOVA on each habituation measure. For the test, the looking time data were log transformed for the parametric analyses, as in Experiments 2 and 3.

Because the two contrasting hypotheses behind this study each make distinct, positive predictions, different analyses were conducted to test each prediction. First, the hypothesis that infants have correct expectations about shadow motion and apply those expectations after detecting shadow motion that violates constraints on objects predicts that the infants in Experiment 4 will look longer at the test events in which the shadow moves unnaturally. This prediction was tested by *t*-tests comparing infants' looking on the last 3 habituation trials with their average looking at each of the two test displays, and by a 2 (condition: 4A vs. 4B) x 3 (trial pair) x 2 (test event: natural vs. unnatural) ANOVA on the test trial looking times of Experiment 4. This prediction was also tested by a Wilcoxon Signed Ranks test comparing total looking at each of the two test displays in Experiment 4.

Second, the hypothesis that infants initially expect shadows to move as objects and then, on detecting motions that violate this expectation, have no consistent expectations about further shadow motions predicts that infants' looking preference between the test displays will be reliably reduced in Experiment 4, relative to the preferences in Experiment 3. This prediction was tested by a 2 (age) x 2 (habituation condition: stationary (Exp. 3) vs. natural shadow motion (Exp. 4)) x 2 (test condition: A vs. B) x 3 (trial pair) x 2 (test event: natural vs. unnatural) ANOVA on the test trial looking times of Experiments 3 and 4. In addition, the differences in total looking at each of the two test displays in Experiments 3 and 4 were compared by Wilcoxon-Mann-Whitney tests conducted for each condition.

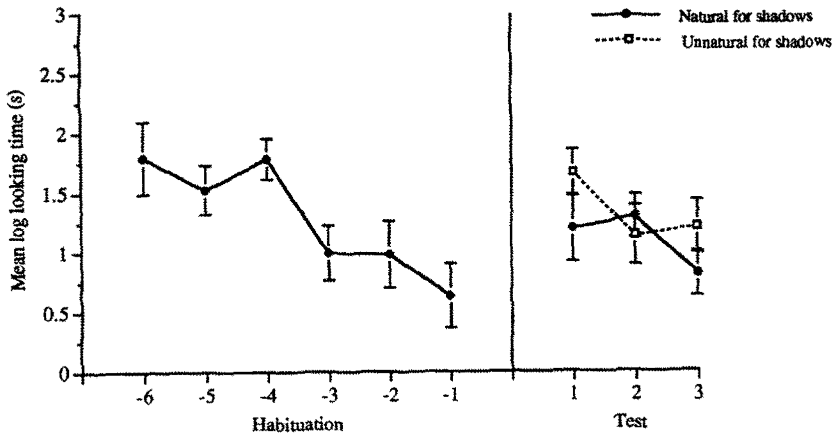
Results

The findings are presented in Table 4 and Figure 6. During the habituation period, infants in Condition 4B tended to look longer during the first 3 habituation trials, $F(1, 28) = 6.44$, $p < .05$, and older infants tended to look longer than younger infants, $F(1, 28) = 4.72$, $p < .05$). Finally, there was an interaction between age and condition for the first 3 trials, $F(1, 28) = 5.10$, $p < .05$. Younger infants in Condition 4A tended to look less than older infants in this condition, while infants in Condition 4B tended to look roughly equally at both ages. No other main effects or interactions on any of the habituation measures approached significance. The comparisons of looking times during the habituation trials of Experiments 3 and 4 revealed that looking times were higher in Experiment 4, in which the display moved during the habituation trials, than in Experiment 3, in which the habituation display was stationary. This difference was obtained for

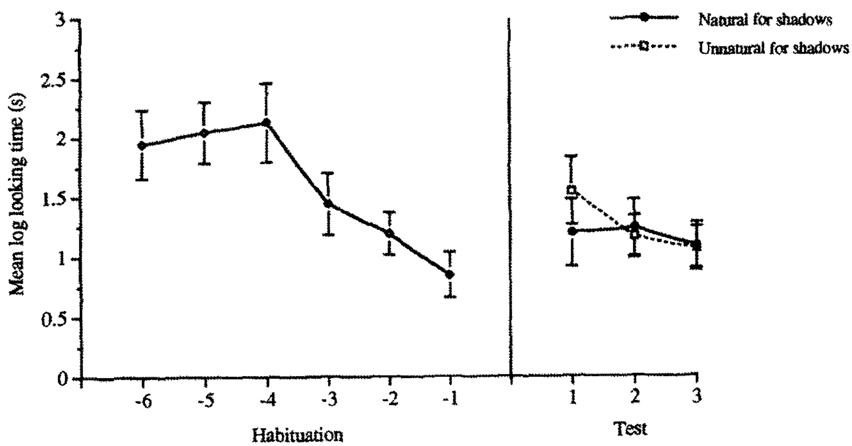
Table 4. Infants' Looking Patterns During Habituation Trials in Experiment 4

	5 months		8 months	
	Cond. A	Cond. B	Cond. A	Cond. B
Log looking time (s), first 3 trials	2.62[a] (0.57)[b]	6.05 (0.62)	5.59 (1.01)	5.99 (0.56)
Log looking time (s), last 3 trials	2.58 (0.65)	3.39 (0.88)	2.66 (0.63)	3.55 (0.97)
Log looking time (s) total	11.97 (1.72)	13.84 (2.39)	12.28 (2.63)	14.80 (2.60)
Trials (no.)	12.00 (1.15)	8.63 (1.13)	9.00 (1.31)	8.88 (1.25)

Notes. [a]mean
[b]standard error



(a)



(b)

Figure 6. Mean log looking times on the last 6 habituation trials and on the 6 test trials of Experiment 4 for infants tested with motion of the ball (Condition 4A, top) and motion of the box (Condition 4B, bottom).

total looking during habituation, ($F(1, 56) = 5.17, p < .05$), and looking on the first 3 habituation trials, ($F(1, 56) = 8.21, p < .01$). In addition, on the sum of the first 3 trials, there was an interaction between experiment and condition, $F(1, 56) = 5.12, p < .05$. Infants in Experiment 4, Condition B tended to look longer on the first 3 trials than those in Condition A, whereas infants in the two conditions of Experiment 3 tended to look equally.

The analyses of dishabituation revealed that infants in Condition 4A dishabituated to the test event that was unnatural for shadows, $t(15) = 2.61, p < .02$ and dishabituated marginally to the test event that was natural for shadows, $t(15) = 1.89$, $p < .08$.[4] Infants in Condition 4B did not dishabituate to either test event, both ts < 1. During the test, the infants in Experiment 4 showed no preferences between the natural and unnatural test events. The ANOVA revealed a significant main effect of age, $F(1, 28) = 8.1, p < .01$, and of trial pair, $F(2, 56) = 3.3, p < .05$, indicating that younger infants looked longer than older infants and that longer looking occurred on the earlier test trials. There were no other significant effects, including no main effect of test event, $F(1, 28) = 2.4, p > .10$ (Figure 6).

The nonparametric analyses revealed no preferences between the test events in Condition 4A (Wilcoxon $T = 49, p > .20$) or Condition 4B (Wilcoxon $T = 56, p > .20$). At 5 months, 6 infants looked longer at the natural events and 10 infants showed the reverse preference; at 8 months, 8 infants looked longer at each test event.

The ANOVA comparing looking preferences in Experiment 4 to those in Experiment 3 revealed main effects of age and habituation condition, respective Fs$(1, 56) = 7.8$ and $11.8, p < .01$, and a main effect of test condition, $F(1, 56) = 4.0, p < .05$: Infants looked longer at the younger age, after habituation to stationary displays, and when watching motions of the ball. This analysis also revealed a main effect of trial pair, $F(2, 112) = 5.3, p < .01$, indicating that looking time declined over trials. Most important, this analysis revealed a significant interaction between habituation condition and test display, $F(1, 56) = 10.9, p < .002$. Whereas infants habituated to the stationary display looked reliably longer at the test events that were inconsistent with the contact principle, those habituated to a display with a naturally moving shadow did not.

Nonparametric tests confirmed this interaction. Infants who were habituated to the natural shadow motion violating no action at a distance showed a lower preference for the test event with natural shadow motion than those habituated to the stationary display, Wilcoxon-Mann-Whitney $z = 1.81, p < .05$, one-tailed. Similarly, infants habituated to the natural shadow motion violating action on contact showed a lower preference for the test event with natural shadow motion than those habituated to the stationary display, Wilcoxon-Mann-Whitney $z = 2.69, p < .01$, two-tailed. Collapsing across conditions, the attenuating effect of habituation to natural shadow motion on preference for shadow motion that violates the contact principle was highly significant, Wilcoxon-Mann-Whitney $z = 3.62, p < .001$.

The infants in Experiment 4 differed from those in Experiment 3 both with respect to their overall looking times during the test trials (those in Experiment 3

[4]Significant dishabituation to the unnatural event did not obtain for infants in this condition when only the first trial was used, $t(15) = 1.35, p > .1$.

Table 5. Low and Hight Total Looking Patterns During Test in Experiment 3 and 4

Experiment and Condition	Low total looking		High total looking	
	natural event	unnatural event	natural event	unnatural event
3A	5.16[a] (0.70)[b]	4.07 (0.71)	7.57 (0.53)	6.65 (0.34)
3B	3.23 (0.64)	2.71 (0.64)	6.16 (0.38)	4.87 (0.45)
4A	2.08 (0.48)	2.67 (0.53)	4.54 (0.55)	5.34 (0.56)
4B	2.48 (0.36)	2.85 (0.47)	4.53 (0.44)	4.66 (0.49)

Notes. [a]mean
[b]standard error

looked longer during the test sequence) and with respect to the amount of change in looking times from habituation to test (those in Experiment 3 showed a greater increase in looking from the habituation to the test sequence). One may ask whether either of these differences contributed to the differing preferences between the test displays shown by the infants in the two experiments. In particular, the longer test trial looking times by the infants in Experiment 3, and the greater increase in looking times from habituation to test in that experiment, may have rendered Experiment 3 a more sensitive test of preferences between the test displays, revealing an intrinsic preference for the natural motion test events that was present, but obscured, in the less attentive infants in Experiment 4. Further analyses addressed this possibility. In one analysis, the total looking time of each infant during the test session was calculated, and the infants in each condition of each experiment were split into two groups at the median looking time for that experiment and condition.[5] Table 5 presents the looking times of high and low looking infants in each experiment and condition. It can be seen that the high lookers in Experiment 4 have somewhat longer looking times than the low lookers of Experiment 3, indicating that the split median analysis succeeded in creating subgroups of infants for whom the general looking time patterns from the main analysis do not hold. Most important, the test trial preferences of infants in Experiments 3 and 4 continue to hold in all the subgroups generated by the median split. The test trial looking times of Experiments 3 and 4 were subjected to an ANOVA comparing the factors habituation condition (Exp. 3 vs. 4), test condition (A vs. B), looking time (high vs. low), trial pair, and test event. This analysis, like those reported above, revealed a habituation by test event interaction, $F(1, 56) = 7.83$, p

[5]Because there were no effects of age in Experiments 3 or 4, infants were partitioned into low and high looking groups without respect to age. In fact, roughly half of the infants in each condition of each experiment fell into each of the two groups: three 5-month-old infants and five 8-month-old infants in condition 3A and four 5-month-old infants and four eight-month-old infants in condition 3B fell into the low looking group. In Experiment 4, five 5-month-old infants and three 8-month-old infants in each of the two conditions fell into the low looking group.

< .005. It did not, however, reveal any interaction between habituation condition, looking time and test event, $F(1, 56) < 1$. Two further split-median analyses, dividing infants in accord with the extent of increase in looking time from the habituation period to the test period, similarly revealed no interaction of this factor with other variables.[6] The differences between looking preferences in Experiments 3 and 4 are therefore not attributable to differences in overall looking times or levels of dishabituation.

Discussion

The habituation preferences of infants in this experiment shed light on the preference of infants in Experiment 3 for test events involving ball motion. Infants in Experiment 4 who were habituated to ball motion tended to look longer during habituation than infants habituated to box motion. This suggests that the main effect of condition in Experiment 3 resulted from an intrinsic preference for this type of event, perhaps because it involved the motion of an object suspended in midair rather than on the stage floor.

After habituation with an event in which a shadow moved naturally in violation of the contact principle, infants at 5 and 8 months showed no consistent preference between new natural and unnatural shadow motions. Preferences for the natural shadow motion in the test sequence were significantly lower than in Experiment 3, in which infants were familiarized with a stationary shadow display. This difference is not attributable to non-specific differences between the looking patterns of infants in the two experiments, such as differences in their overall level of looking time. It provides evidence that infants detected the natural shadow motion during the habituation period and suggests that infants interpreted this motion in either of two ways. First, after habituation to one violation of the contact principle, infants may no longer have inferred that the shadow would move in accord with constraints on material objects, and so suspended application of the contact principle to the new motion of the shadow. Second, because the shadow moved independently of the surface with which it was in contact, infants may have interpreted the shadow as a third, independently movable object. In this

[6]The increase in looking time from the habituation trials to the test trials was assessed in two ways. First, each infant's looking time on the last habituation trial was subtracted from his or her looking time on the first test trial to obtain a measure of the immediate increase in attention at the start of the test sequence. Second, each infant's looking time on the last 3 habituation trials was subtracted from his or her looking time on all 6 test trials to obtain a measure of the overall rise in looking during the test sequence. In each case, split-median analyses like that described in the text were performed comparing Habituation Condition (Exp. 3 vs. 4), Test Condition (A vs. B), Looking Time (high vs. low), Trial Pair, and Test Display. These analyses revealed results entirely consistent with those reported in the text. Both revealed a Habituation x Test Event interaction ($F(1,56) = 10.89$ and 10.71 respectively, $p < .005$). Neither analysis revealed an interaction of Habituation Condition and Looking Time with Test Event ($Fs(1,56) < 1$).

case, the two test displays would have been perceived as equally consistent with the contact principle.

Nevertheless, the preferences of Experiment 4 did not reverse with respect to those of Experiment 3. Although it remains possible that more extensive exposure to natural shadow motions would produce different findings, the absence of preferences for the unnatural shadow motion in Experiment 4 suggests that infants did not reason about the shadow's behavior by drawing on knowledge of how shadows move. This finding is consistent with the suggestion, from studies of older children, that children have no understanding of the ways in which shadows violate constraints on material objects (e.g., deVries, 1987).

Why did infants fail to reason correctly about the shadow in Experiment 4? It is possible that infants are predisposed to attend to the motions of perceptible entities that are in contact: Thus, infants may have noticed the motion relations between the shadow and box that violated the contact principle but not have noticed the relation between the shadow and ball. Alternatively, infants may have attended to the motion relations among all three entities. When these motions violated the contact principle during the habituation trials, however, infants may have suspended all predictions about their future motions. On either interpretation, infants' focus on contact relations would preclude correct reasoning about the motion of the shadow.

General Discussion

The present experiments support three conclusions. First, infants are able to perceive and attend to moving shadows, at least under the conditions of these experiments. In Experiments 2 and 3, infants showed reliable looking preferences between two visual displays that were identical except for the motions of a shadow. Infants evidently do not possess a filtering mechanism that prevents their perceiving shadow motions. Second, infants perceive shadow motions in accord with the principle of contact. Because this principle applies to objects but not to shadows, infants appear to overgeneralize their knowledge of object motions to entities that adults recognize as shadows. This overgeneralization is evident in Experiment 3, in which infants looked longer at natural shadow motions in violation of the contact principle than at unnatural shadow motions in accord with that principle. Third, infants do not reason correctly about shadow motion, even following habituation to an event in which the shadow behaves naturally. In Experiment 4, infants who viewed the shadow moving separately from the box may have suspended the contact principle and made no inferences about the shadow's motion, or they may have used the contact principle to perceive the shadow as a separate object whose two test motions were equally plausible. In either case, however, infants evidently were not led, by repeated exposure to a natural shadow motion, to make correct predictions about further motions of the shadow.

The present findings are consistent with the findings of studies of older children's explicit reasoning about shadow phenomena. Like the studies of Piaget (1960, 1962), deVries (1987), and Carey (1991; Smith et al., 1985), these experiments suggest that young children have no consistent understanding of shadows and overextend to shadows knowledge that guides their reasoning about material objects. Because children of all ages show substantially more appropriate reasoning about the behavior of material objects, it appears that the development of knowledge of objects long precedes the development of knowledge of the shadows that objects cast.

The large differences in the rate of development of knowledge of objects and shadows cannot be explained entirely by differences in the input that children receive. A learner who attended equally to all contrast borders in a visual array probably would be confronted with as many shadows as objects. If he or she devoted equal effort to learning to predict the motions of all the entities defined by closed contrast borders, he or she would be unlikely to converge on principles of motion that apply to objects but are violated by shadows. The present findings therefore suggest that human infants and children are predisposed to develop knowledge about material objects in preference to knowledge about shadows.

This predisposition might be explained in two quite different ways. First, infants and children may have perceptual or attentional systems that are especially attuned to objects, allowing them to filter out most information about shadows. Although the present experiments cast doubt on extreme versions of this thesis, because infants did attend to and discriminate arrays that differed only with respect to shadow motions, weaker versions of the thesis are possible. Infants may be less sensitive to shadows than to objects and therefore receive disproportionate input from the latter. The challenges faced by this view are two-fold: It must indicate (1) how such a perceptual attenuation process takes place, and (2) how, given full input from objects and attenuated input from shadows, infants induce principles governing objects' behavior that are violated by shadows. The latter task will be challenging, because infants have been found to possess knowledge about the behavior of objects as early as 3 months of age (Baillargeon, 1993, 1995), before they can reach for and manipulate objects, perceive objects with high resolution, or follow object motions adeptly. If knowledge about objects develops through learning, the learning process must be rapid enough to proceed on the minimal input available to young infants, and yet gradual enough not to be perturbed by the conflicting input about motion provided by shadows.

A second account roots infants' predisposition to develop knowledge about material objects in the child's emerging systems of knowledge themselves. Although infants may detect shadows as well as objects, they may be predisposed to reason about the perceptible world in terms of principles governing objects' behavior. Confronted with entities whose behavior accords with these principles (objects, surface markings), infants may apply their principles with success and develop further knowledge about those entities. Confronted with entities whose behavior fails to accord with these principles (shadows, sounds, and in some cases, nonsolid substances), infants would fail to predict the entities' behavior and therefore would fail to learn about them.

Although we believe the weight of the evidence from studies of infants and children favors the latter view, we regard this question as unresolved and highly worthy of further exploration. Shadows are natural, perceptible entities whose behavior fails to accord with many constraints on objects. When a child's verbal judgment or an infant's looking preference suggests that he or she views a shadow's familiar and natural behavior as unfamiliar, unnatural, or even surprising, these reactions provide a special window on the child or infant's mind: They help reveal the expectations that the infant or child brings to the phenomena she perceives, as distinct from the expectations he or she draws from those phenomena.

In this respect, infants' overgeneralization of principles capturing the behavior of material objects to shadows resembles a well-studied phenomenon in language acquisition: the overgeneralization of morphological rules to exceptional cases (as, for example, when a child says "two foots" or "I runned"). Although the explanation for morphological errors continues to be debated (see, for example, Marcus, Pinker, Ullman, Hollander, Rosen, & Xu, 1992; McClelland, 1988), the existence of such errors indicates unequivocally that the child's developing knowledge of language does not faithfully mirror the input she receives but instead reflects properties of the child's own systems for organizing and making sense of that input. The present experiments suggest that phenomena of overgeneralization are not limited to language acquisition or to explicit reasoning processes in older children. Studies of infants' overgeneralization of physical principles therefore may shed light on fundamental properties of the cognitive system by which children first make sense of the physical world.

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