Developmental Science 3:3 (2000), pp 344–359

PAPER

Reasoning about collisions involving inert objects in 7.5-month-old infants

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Abstract

The present research asked whether 7.5-month-old infants realize that an object cannot displace another object without contacting it. The infants in Experiment 1 were assigned to a contact or a no-contact condition. The infants in the no-contact condition saw static familiarization displays in which a tall, thin barrier stood across the bottom of a ramp; a cylinder rested against the left side of the barrier and a wheeled toy bug against its right side. The infants in the contact condition saw similar displays except that a large portion of the barrier's lower half was removed so that the cylinder rested directly against the bug. Next, a small screen was placed in front of the bottom of the ramp; only the upper portion of the barrier was visible above the screen. The infants in the two conditions watched the same test event. The cylinder was released and rolled to the bottom of the ramp, partly disappearing behind the screen's left edge; next, the bug rolled down the track, as though launched by the cylinder. The infants in the no-contact condition looked reliably longer at the test event than did those in the contact condition. This result suggested that the infants (a) viewed the bug as an inert object that could move only when acted upon; (b) believed that the cylinder could not act on the bug without contacting it; (c) realized that the cylinder could contact the bug when the half-barrier but not the barrier was present; (d) remembered after the screen was raised whether contact was possible between the cylinder and bug; and (e) were surprised in the no-contact condition when the bug was launched down the track. A second experiment confirmed the results of Experiment 1. Previous research comparing infants' responses to no-contact and contact events has typically made use of self-moving rather than inert objects. These experiments have consistently found that infants do not look reliably longer at no-contact than at contact events. In the General Discussion, we examine the contrast between these prior results and the present results and speculate on how infants' expectations about inert and self-moving objects may be best characterized.

Traditionally, researchers assumed that infants understand very little of the physical events that take place around them (e.g. Piaget, 1952; 1954). With the advent of new methodologies, however, investigators came to realize that infants do possess expectations about the physical world (e.g. Leslie, 1982; Baillargeon, Spelke & Wasserman, 1985; Pieraut-Le Bonniec, 1985; Hood & Willatts, 1986). This discovery has led researchers in recent years to systematically explore infants' expectations about many different types of physical events, including occlusion (e.g. Baillargeon & DeVos, 1991; Van de Walle & Spelke, 1996; Wilcox & Baillargeon, 1998; Aguiar & Baillargeon, 1999), containment (e.g. Kolstad, 1991; Sitskoorn & Smitsman, 1995; Aguiar & Baillargeon, 1998; Hespos & Baillargeon, in press), support (e.g. Baillargeon, Needham & DeVos, 1992; Spelke, Breinlinger, Macomber & Jacobson, 1992; Needham & Baillargeon, 1993; Sitskoorn & Smitsman, 1997) and collision (e.g. Leslie, 1982, 1984; Cohen & Oakes, 1993; Kotovsky & Baillargeon, 1994; Oakes, 1994) events. The present research was conducted as a part of this general effort to bring to light infants' physical knowledge and focused on 7.5-month-olds' understanding of collision events.

In an earlier experiment (Kotovsky & Baillargeon, 1994), we found that, by 11 months of age, infants already possess sophisticated expectations about collision events: when shown an event in which a first object

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collides with and displaces a second object, infants expect the size[1] of the first object to affect how far the second object is displaced. The infants in this experiment sat in front of a long horizontal track; to the left of the track was an inclined ramp. A large wheeled toy bug stood on the track at the bottom of the ramp. To start, the infants were familiarized with an event in which a medium cylinder rolled down the ramp and hit the bug, propelling it to the middle of the track. Next, the infants saw two test events. In one, the medium cylinder was replaced with a larger cylinder that propelled the bug to the end of the track. In the other event, the medium cylinder was replaced with a smaller cylinder that also propelled the bug to the end of the track. The infants looked reliably longer at the small-cylinder than at the large-cylinder test event. These and control results indicated that the infants (a) expected the distance traveled by the bug to be proportionally related to the cylinder's size and (b) were surprised in the small-cylinder event when this expectation was violated.

The finding that 11-month-old infants are already capable of sophisticated reasoning about collision events suggested that younger infants might possess at least simple expectations about these events. The present research asked whether 7.5-month-old infants realize that an object cannot displace another object without contacting it. The experiments made use of an experimental situation similar to that in our initial research (Kotovsky & Baillargeon, 1994). The question of interest was whether the infants would realize that the cylinder could not set the bug in motion without contacting it. Before describing this research, we first discuss prior results from the infancy literature; an apparent discrepancy in these results contributed to the design of the present experiments.

Infants' responses to contact and no-contact events

Over the past 15 years, several experiments have compared infants' responses to contact and no-contact events (e.g. Leslie, 1982, 1984; Oakes & Cohen, 1990, 1991; Oakes, 1994). In a *contact* event, a first object approaches and contacts a second object, which is then displaced; in a *no-contact* event, the first object approaches but stops short of the second object, which is nevertheless again displaced. The experiments have examined infants aged from 4.5 to 10 months using a wide variety of objects (e.g. bricks, balls or toy vehicles) and presentation modes (e.g. filmed, videotaped or computer-generated events). Despite these differences, the experiments have yielded highly consistent results. To illustrate these results, we briefly describe two experiments, one by Leslie (1982) and another by Oakes (1994).

Leslie (1982) habituated 4.5-month-old infants to one of two filmed events: (a) a contact event in which a red brick approached and collided with a green brick, setting it in motion; and (b) a no-contact event in which the red brick stopped 6 cm short of the green brick, which again moved off immediately after the red brick came to a stop. Following habituation, the infants saw a test event in which the red brick remained stationary and the green brick moved off as before. The infants habituated to the contact event dishabituated reliably more to the test event than did those habituated to the no-contact event.

Oakes (1994) habituated 7-month-old infants to one of three computer-generated events: (a) a contact event in which a blue ball approached and contacted a red ball, which immediately moved off; (b) a no-contact event in which a 12 cm gap separated the motions of the first and second ball; and finally (c) a delay event in which a 0.75 s delay separated the two balls' motions. The infants habituated to the contact event dishabituated to both the no-contact and delay events, but the infants habituated to the no-contact or delay event tended to dishabituate only to the contact event.

The results of these and related experiments (e.g. Leslie, 1984; Oakes & Cohen, 1990, 1991) suggest that infants aged 4.5 months and older distinguish between simple causal and non-causal events. When shown an event in which an object collides with another object, which is immediately displaced, infants conclude that the first object causes the second object's motion. Infants do not draw the same conclusion, however, when the two objects' motions are separated by a spatial or temporal gap.

In addition to demonstrating infants' sensitivity to the causal properties of events, the experiments reviewed in this section provide evidence that infants appreciate that an object cannot displace another object without contacting it: in no-contact events, infants do not view the first object as the cause of the second object's motion.

An apparent discrepancy

The conclusions presented in the previous section are those suggested by the experiments' *test* data (e.g. Leslie, 1982, 1984; Oakes & Cohen, 1990, 1991; Oakes, 1994). Examination of the same experiments' *habituation* data gives rise to an apparent discrepancy. Leslie (1982)

[1] We refer to the first object's size rather than mass because the data we collected were insufficient to determine which of these two variables guided the infants' responses (Kotovsky & Baillargeon, 1994).

reported that the infants in his experiment tended to look equally during habituation whether they saw the no-contact or the contact event. Similarly, Oakes (1994) found that her infants looked about equally during habituation whether they saw the contact, no-contact, or delay event. The same negative finding was obtained in the other experiments as well (e.g. Leslie, 1984; Oakes & Cohen, 1990, 1991).

What should we make of these negative results? When shown two events, one they view as expected and one as unexpected, infants typically look longer at the unexpected event (e.g. Baillargeon & Graber, 1988; Baillargeon, Graber, DeVos & Black, 1990; Needham & Baillargeon, 1993). Hence, the fact that infants looked about equally during habituation whether they were presented with a no-contact or contact event (e.g. Leslie, 1982, 1984; Oakes & Cohen, 1990, 1991; Oakes, 1994) suggests that they did *not* perceive the no-contact event as unexpected. But if infants realized, as evidenced by their test responses, that an object cannot set another object in motion without contacting it, should they not have viewed the no-contact event as unexpected? How can we reconcile the experiments' positive test findings with their negative habituation data?

The explanation for this apparent discrepancy, we believe, has to do with the nature of the objects used in the experiments. As adults, we distinguish between inanimate objects that are *inert* and incapable of self-motion (e.g. cups, balls, pens), and inanimate objects that are *self-moving* and capable of at least limited self-motion (e.g. cars, ceiling fans, mechanical mobiles and toys). Most adults would be surprised to see no-contact events involving inert but not self-moving objects. To illustrate, consider the following events: (a) a club approaches but stops short of a golf ball, which is nevertheless displaced; and (b) a car approaches and stops short of another car, which then moves away. We would perceive the first but not the second of these events as surprising: we realize that golf balls move only when acted upon and that clubs must contact balls in order to act on them; at the same time, we recognize that cars can move spontaneously, without being acted upon by other objects.

All of the experiments discussed above (e.g. Leslie, 1982, 1984; Oakes & Cohen, 1990, 1991; Oakes, 1994) used self-moving objects: the first object always initiated its own motion, in plain view of the infants. Furthermore, the first and second objects typically moved at a constant speed. Hence, one explanation for the experiments' negative habituation data is that infants (a) categorized the first object as self-moving, upon seeing it initiate its own motion; (b) assumed that the second object, which greatly resembled the first, was also self-moving; (c) judged in the contact event that the first object caused the second object's motion;[2] and (d) inferred in the no-contact event that the second object simply caused its own motion.

Implicit in the preceding analysis are several hypotheses concerning infants' responses to inert and self-moving objects; here we simply state three of these hypotheses and discuss them more fully in the General Discussion. First, we suspect that, in the course of development, infants come to distinguish between inert and self-moving inanimate objects. Self-moving objects are capable of a wider range of behaviors than are inert objects: they can initiate their motion, they can alter their path (e.g. reverse course), they can maintain or even increase their speed, and so on. In contrast, inert objects can begin to move, alter their course, maintain or increase their speed, and so on, only when acted upon by external forces. Presumably, as they observe the displacements of inert and self-moving objects, infants identify more and more precisely the range of behaviors that each type of object can perform. Second, we believe that infants view objects as inert unless given clear and unambiguous information to the contrary: the default assumption when categorizing objects is always that they are inert. It is only when confronted with a behavior that has been identified as characteristic of self-moving objects (e.g. when seeing an object begin to move on its own, or reverse its course in the absence of any external force) that infants abandon their default assumption and categorize the object as self-moving. Once an object has been categorized as self-moving, it is expected to be able to engage in the full range of behaviors that has been identified as characteristic of self-moving objects; the category assignment thus carries weight in terms of predicting and interpreting the object's future behavior. Finally, we suppose that infants may categorize an object as self-moving if it is perceptually similar to another object in the same situation that has already been categorized as self-moving. Recent evidence indicates that young infants are extremely adept at forming perceptual categories (e.g. Quinn & Eimas, 1996; Needham & Modi, 2000). It seems likely that infants would view objects belonging to the same perceptual category as capable of the same range of behaviors.

In conclusion, our interpretation of the existing research on infants' responses to contact and no-contact events (e.g. Leslie, 1982, 1984; Oakes & Cohen, 1990, 1991; Oakes, 1994) can be summarized as follows. When

[2] We suppose that infants have no difficulty with the notion that self-moving objects, like other objects, can be acted upon and set into motion.

shown a contact and a no-contact event involving self-moving objects in habituation trials, infants tend to look equally at the events because they can generate an explanation, in each event, for the second object's motion: it is thought to be caused by the first object in the contact event, and to be self-caused in the no-contact event. If, after being habituated to one event (e.g. a contact event), infants are tested with the other event (e.g. a no-contact event), they dishabituate because they detect the change in the cause of the second object's motion. Together, these results suggest that infants are sensitive to the causal properties of events, and also recognize that objects cannot cause other objects to move without contacting them.

Experiment 1

Experiment 1 sought further evidence that infants realize that objects cannot displace other objects without contacting them. In the last section, we suggested that infants in previous experiments (e.g. Leslie, 1982, 1984; Oakes & Cohen, 1990, 1991; Oakes, 1994) did not view the no-contact event they were shown in habituation trials as unexpected because they categorized the objects involved in the event as self-moving. This analysis predicts that infants should respond differently if shown a no-contact and a contact event involving *inert* as opposed to self-moving objects. Infants should now view the no-contact event as unexpected or surprising and hence should look reliably longer at it than at the contact event. The present experiment was designed to test this prediction: it compared 7.5-month-olds' responses to a no-contact and a contact event involving inert objects.

One concern in designing the experiment was that infants might prefer the no-contact event, not because it violated their beliefs about collision events, but because it somehow presented a more attractive spatiotemporal trajectory than the contact event. Our solution was to present infants with *occluded* no-contact and contact events. Infants could determine whether they were faced with a no-contact or a contact event only on the basis of information received *prior* to the event. Because the occluded no-contact and contact events were perceptually identical, a preference for the no-contact event could not be attributed to superficial characteristics of the event. Such a preference could arise only because the no-contact event violated infants' belief that an object cannot displace another object without contacting it.

The infants in Experiment 1 were assigned to either a no-contact or a contact condition (see Figure 1). The apparatus was similar to that used by Kotovsky and Baillargeon (1994). The infants in both conditions sat facing the middle of a track; to the left of the track was an inclined ramp. The infants in the *no-contact* condition first saw two static familiarization displays in which a tall, thin barrier stood across the bottom of the ramp. In the first display, a cylinder rested at the bottom of the ramp against the left side of the barrier; a wheeled toy bug was visible at the far end of the track.[3] The second display was identical to the first except that the bug now rested against the right side of the barrier (when in this position, the bug naturally occluded a portion of the lower half of the barrier; this is why the bug was positioned at the end of the track in the first display, to give the infants the opportunity to inspect the whole of the barrier). The infants in the *contact* condition saw similar familiarization displays except that the barrier was replaced with a half-barrier. The upper portion of this half-barrier was identical to that of the barrier, but most of its lower portion was removed (all but a thin leg at the far edge). In the second familiarization display, the cylinder rested against the bug, beneath the half-barrier. The familiarization displays shown in the two conditions were thus intended to make clear to the infants that contact between the cylinder and bug was prevented by the barrier in the no-contact condition, and was possible beneath the half-barrier in the contact condition.

Following the familiarization trials, a small screen was placed in front of the bottom of the ramp. Only the upper portion of the barrier or half-barrier was visible above the screen (in fact, the half-barrier was used in both conditions, to equate sound cues; since the upper portions of the two barriers were identical, they were not distinguishable with the screen in place). The infants in the no-contact and contact conditions saw the same test event. At the beginning of the event, the cylinder was held by an experimenter's hand at the top of the ramp; the bug rested on the track at the bottom of the ramp and was partly visible to the right of the screen. The

[3] Readers might wonder why we used the wheeled toy bug from our previous experiment (Kotovsky & Baillargeon, 1994) as one of the inert objects in Experiment 1. There were several reasons for this selection. First, because the bug was highly idealized and fanciful, it was not clear infants would even realize that it was meant to represent an animal of some kind; it seemed more likely that infants would categorize it as a novel inanimate object. Second, we suspected that behavioral information (how objects move and interact) is more important than featural information for infants in determining whether a novel inanimate object is inert or self-moving. Finally, even if infants did attend to the bug's featural properties, the nature of the materials used (e.g. Styrofoam painted blue, synthetic blue hair, white lace) seemed more likely to suggest an inert object. In any event, the results of Experiments 1 and 2 make clear that infants did view the bug as an inert object.

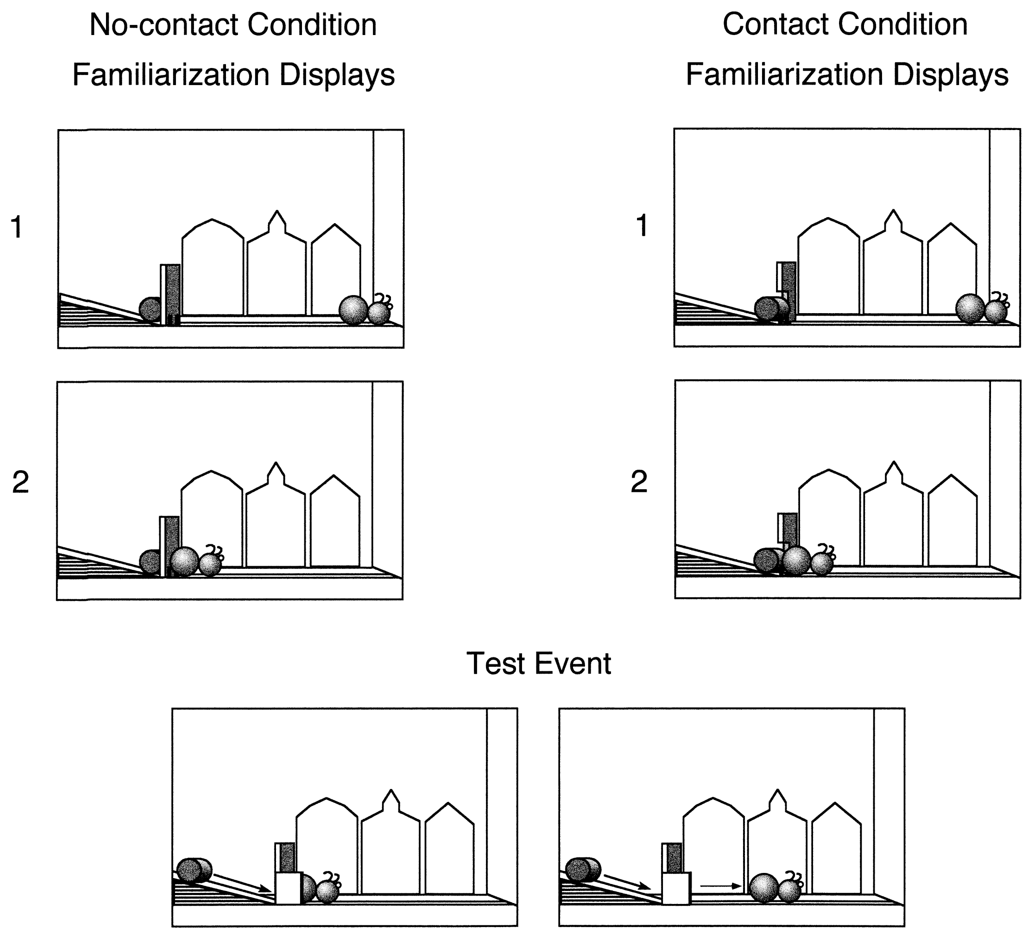

Figure 1 *Schematic drawing of the familiarization displays and test event shown to the infants in the no-contact and contact conditions of Experiment 1.*

cylinder was released and rolled to the bottom of the ramp, partly disappearing behind the left edge of the screen. Next, the bug rolled to the middle of the track, as though launched by the cylinder.

Our reasoning was as follows. If the infants (a) viewed the bug as an inert object that could move only when acted upon; (b) believed that the cylinder could not act on the bug without contacting it; (c) realized that the cylinder could contact the bug when the half-barrier but not the barrier was present; and (d) remembered after the screen was raised whether contact was possible between the cylinder and bug, then the infants in the no-contact condition should be surprised when the bug rolled down the track, but the infants in the contact condition should not. The infants in the no-contact condition were thus expected to look reliably longer at the test event than those in the contact condition.

Method

Participants

Participants were 16 healthy term infants ranging in age from 7 months 0 day to 7 months 28 days (M = 7 months 9 days). Half of the infants were randomly assigned to the no-contact condition (M = 7 months 9 days) and half to the contact condition (M = 7 months 10 days). There were equal numbers of males and females in each condition. An additional three infants were tested but eliminated, two because of apparatus failure and one because of experimenter error. The infants' names in this and the following experiment were obtained from birth announcements in the local newspaper. Parents were contacted by letters and follow-up phone calls. They were offered reimbursement for their travel expenses but were not compensated for their participation.

Apparatus and stimuli

The apparatus consisted of an unpainted wooden box 122.5 cm high, 152 cm wide and 52 cm deep that was mounted 80.5 cm above the room floor. The infants faced an opening 52.5 cm high and 150 cm wide in the front of the apparatus. The apparatus's back wall was covered with pink poster board and decorated with pictures of a barn, a church and a house. The three buildings were arranged in a row 8.5 cm above the apparatus floor; the barn was positioned 50 cm from the left wall and the house 1 cm from the right wall. Immediately below the buildings was an opening 8.5 cm high and 91 cm wide that was partly concealed by a dark blue fringe.

A wooden ramp 56 cm long and 13.6 cm wide stood against the apparatus's left wall, below an opening 21 cm high and 15 cm wide that was filled with white fringe. The ramp was covered with black contact paper and was positioned 28 cm from and parallel to the front of the apparatus. At the top of the ramp was a plateau 7.6 cm high and 16 cm long; the ramp itself sloped downward at an 11° angle. A cylinder 5.9 cm in diameter and 13.4 cm wide could be rolled down the ramp. The cylinder was closed at both ends, was made of plastic piping material and was painted light blue. It was manipulated by a right hand wearing a black glove 61.5 cm long; the hand entered the apparatus through the opening in the left wall at the top of the ramp. The sides of the ramp were covered with panels of wood 0.5 cm thick that were cut to protrude 0.75 cm above the ramp. These side panels prevented the cylinder from rolling off the ramp. The ramp and its side panels were mounted on a strip of particle board 0.7 cm thick, 56 cm long and 15.5 cm wide. At the bottom of the ramp and positioned 10.5 cm apart were two upright metal posts that prevented the cylinder from rolling onto the track. Each post was 10.5 cm high and 1.25 cm in diameter and was covered with black felt.

During the familiarization trials, a wooden barrier (no-contact condition) or half-barrier (contact condition) stood across the bottom of the ramp, immediately to the left of the posts. Both barriers were 29.6 cm high, 17.8 cm wide and 1.3 cm thick; they were painted white and decorated with green and blue dots. The far edge of each barrier was inserted in a metal bracket that kept it rigidly upright. The half-barrier had an opening 18.4 cm high and 15.9 cm wide in its lower near portion. During the test trials, the half-barrier was used in both the no-contact and contact conditions, to ensure that the sound cues available to the infants and observers were identical in the two conditions. A small cardboard screen 23.3 cm high and 18.4 cm wide and covered with a patterned green contact paper was affixed to the front of the half-barrier to hide its lower portion; the top 6.3 cm of the half-barrier protruded above the screen. The left edge of the screen was aligned with that of the half-barrier.

Centered at the bottom of the ramp was a model train track 5 cm wide. The track was 96 cm long and covered the full length of the apparatus from the bottom of the ramp to the right wall. The track rested on a strip of particle board 0.7 cm thick and 15.5 cm wide that was covered with black felt.

A brightly colored toy bug 15 cm high, 22 cm long and 13 cm wide was mounted on model train wheels and rested on the track. The bug consisted of two Styrofoam balls decorated with long blue fur; the front, smaller ball sported eyes and antennae, and the rear, larger ball was partly covered with a white flounced skirt. When the bug was placed at the bottom of the ramp, its rear portion extended between the two posts. Although the cylinder contacted the bug in the test event, its impact was insufficient to propel the bug. A special propulsion system was used to launch the bug, to ensure that it rolled the same distance consistently within and across trials. When the bug was in position between the posts, its rear portion rested against a metal lever 0.6 cm wide and 0.6 cm deep that protruded 3 cm above the apparatus floor. The lever was controlled by a micro-switch set in the floor of the ramp. The switch was located 4 cm from the bottom of the ramp and was triggered by the cylinder as it rolled down the ramp. When triggered, the switch activated a solenoid located beneath the apparatus floor; the solenoid in turn activated the lever, causing it to hit the bug. Because the lever hit the bug with the same force each time it was activated, the bug travelled the same distance each time it was launched. The lever's activity was difficult to detect: even with no screen present, adult subjects failed to notice it, despite repeated viewings, and assumed that the cylinder caused the bug to roll down the track (Kotovsky & Baillargeon, 1994). After the bug rolled to a stop, a left hand wearing a cream-colored glove 65.5 cm long reached through the opening in the apparatus's back wall and repositioned the bug between the posts.

The infants were tested in a brightly lit room. Four 40 W clip-on lights attached to the apparatus's front wall provided additional light. Two muslin-covered frames, each 183 cm high and 71 cm wide, stood at an angle on either side of the apparatus. These frames served to isolate the infant from the experimental room. At the end of each trial, a curtain consisting of a muslin-covered frame 63 cm high and 150 cm wide was lowered in front of the apparatus.

Events

Contact condition: familiarization displays The infants in the contact condition saw two familiarization displays (see Figure 1). In the first, the cylinder rested at the bottom of the ramp against the posts, under the half-barrier; the small screen lay flat on the apparatus floor in front of the half-barrier, and the bug was visible at the end of the track against the apparatus's right wall.[4] The second familiarization display was identical except that the bug stood between the posts at the bottom of the ramp, next to the cylinder. The infants saw the two displays in two successive familiarization trials. At the end of each trial, an experimenter lowered the curtain in front of the apparatus, which was then readied for the next trial.

Contact condition: test event Prior to the test trials, the small screen was raised and affixed to the half-barrier; the front portion of the bug was visible to the right of the screen. At the start of each test trial, the cylinder rested on the apparatus floor, 5.5 cm (at its closest point) in front of the ramp and 33 cm (again, at its closest point) from the left wall; the cylinder lay at an angle so that one of its ends faced the infant. Two experimenters worked in concert to produce the test event. The first wore the black glove and manipulated the cylinder; the second wore the cream-colored glove and manipulated the bug. Numbers in parentheses indicate the time taken to perform the actions described.

Each test trial began with a brief pretrial during which the black glove tapped on the cylinder at the rate of about three taps per second until the computer signaled that the infant had looked at the cylinder for four cumulative seconds. At the end of the pretrial, the black glove grasped the cylinder and lifted it to the plateau at the top of the ramp (2 s). The black glove then moved the cylinder to the inclined portion of the ramp and released it (1 s). The cylinder rolled to the bottom of the ramp (1 s) and hit the bug and posts behind the screen (the left portion of the cylinder remained visible to the left of the screen). The bug was propelled down the track and rolled to a stop about 45 cm from the bottom of the ramp (1 s). After a 4 s pause, the black glove, which had been resting at the top of the ramp, reached down (1 s) and lifted the cylinder back to the top of the ramp (1 s). Next, the cream-colored glove entered the apparatus through the opening in the back wall, grasped the bug (1 s), gently pushed it back to the bottom of the ramp (2 s), and exited the apparatus (1 s). The black glove again released the cylinder, beginning a new event cycle. Each cycle (except for the initial cycle, in which the cylinder was first tapped and then lifted to the top of the ramp) thus lasted about 13 s. Cycles were repeated without pause until the computer signaled that the trial had ended (see below). When this occurred, the curtain was lowered in front of the apparatus.

No-contact condition: familiarization displays The familiarization displays in the no-contact condition were identical to those in the contact condition except that the half-barrier was replaced with the full barrier. The cylinder now rested against the left side of the barrier, instead of against the posts; and the bug (in the second familiarization display) now rested against the right side of the barrier instead of against the cylinder.

No-contact condition: test event The test event in the no-contact condition was identical to that in the contact condition (recall that during the test trials the half-barrier was used in both conditions; since the cylinder always hit the bug and posts, auditory cues were identical in the two conditions).

Procedure

Prior to the beginning of the experiment, each infant was shown the cylinder and the two gloves for a few minutes while the parent filled out consent forms. During the experiment, the infant sat on the parent's lap in front of the apparatus, facing the middle of the track. The infant's head was approximately 80 cm from the track. Parents were asked not to interact with their infant while the experiment was in progress, and to close their eyes during the familiarization and test trials.

The infant's looking behavior was monitored by two observers who watched the infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers were not told and could not determine whether the barrier (no-contact condition) or the half-barrier (contact condition) was used in the familiarization trials. Each observer held a button connected to a Dell computer and depressed the button when the infant attended to the events. The looking times recorded by the primary observer were used to determine when a trial had ended (see below).

Each trial was divided into 100 ms intervals, and the computer determined in each interval whether the two observers agreed on the direction of the infant's gaze. Inter-observer agreement was calculated for each test

[4] In principle, the bug could have been left out of the apparatus during the first familiarization trial. We placed the bug at the end of the track to keep the interval between the two familiarization trials as short as possible: it took far less time to roll the bug back to the bottom of the ramp than it did to insert the bug into the apparatus and test that its wheels were correctly aligned on the track.

trial on the basis of the number of intervals in which the computer registered agreement, out of the total number of intervals in the trial. Agreement averaged 96% per trial per infant.

During the *familiarization* phase of the experiment, the infants saw the two familiarization displays appropriate for their condition on two successive trials. Each trial ended when the infant either (a) looked away from the display for two consecutive seconds after having looked at it for at least five cumulative seconds or (b) looked at the display for 60 cumulative seconds without looking away for two consecutive seconds.

During the *test* phase of the experiment, the infants saw the test event on six successive trials. Each trial ended when the infant (a) looked away from the event for two consecutive seconds after having looked at it for at least seven cumulative seconds (beginning at the end of the pretrial, when the cylinder was placed at the top of the ramp) or (b) looked at the event for 60 cumulative seconds without looking away for two consecutive seconds. The 7 s minimum value was chosen to ensure that the infants had ample opportunity to observe that the bug was displaced after the cylinder rolled to the bottom of the ramp.

Preliminary analyses revealed no significant effect of sex on the looking times of the infants in the no-contact and contact conditions at the test event (all $F < 1.40$, all $p > 0.25$); the data were therefore collapsed across sex in subsequent analyses.

Results and discussion

Familiarization trials

The infants' looking times during the familiarization trials (see Figure 2) were analyzed by means of a 2×2 mixed-model analysis of variance (ANOVA) with condition (no-contact or contact) as a between-subjects factor and with trial (1, 2) as a within-subject factor. The main effect of condition was not significant, $F(1, 14) = 0.40$, nor was the condition $\times$ trial interaction, $F(1, 14) = 0.89$, suggesting that the infants in the no-contact and contact conditions did not differ reliably in their responses to the familiarization displays.

Test trials

The infants' looking times during the test trials (see Figure 2) were analyzed by means of a 2×6 mixed-model ANOVA with condition (no-contact or contact) as a between-subjects factor and with trial (1–6) as a within-subject factor. The analysis yielded a significant main effect of condition, $F(1, 14) = 10.64$, $p < 0.01$, indicating that the infants in the no-contact condition ($M = 53.6$, SD = 13.1) looked reliably longer at the test event than did those in the contact condition ($M = 39.0$, SD = 18.6). No other effects were significant (all $F < 1.25$, all $p > 0.25$).

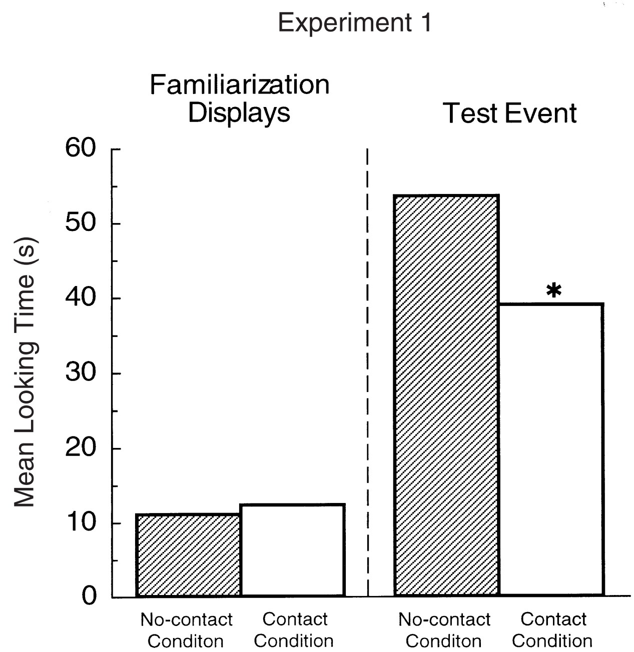

Figure 2 *Mean looking times of the infants in the no-contact and contact conditions of Experiment 1 at the familiarization displays and test event.*

The results of Experiment 1 suggest that the infants (a) assumed that the bug was an inert object that could move only when acted upon; (b) believed that the cylinder could not act upon the bug without contacting it; (c) realized that the cylinder could contact the bug when the half-barrier but not the barrier was present; (d) remembered whether contact was possible between the cylinder and bug after the screen was raised; and hence (e) were surprised in the no-contact but not the contact condition when the bug was launched down the track.

These findings point to two conclusions. First, 7.5-month-old infants realize that an inert object cannot set another inert object in motion without contacting it, and they are surprised when this expectation is violated. Second, infants' differential responses to no-contact and contact events involving inert objects cannot be attributed to low-level perceptual differences between the events. The infants in the no-contact and contact conditions saw exactly the same test event and yet they responded to it differently depending on the information they had received in the familiarization trials.

To provide further support for these conclusions, 7.5-month-old infants were examined in Experiment 2 using a test event similar to that of Experiment 1, except that the bug remained stationary after the cylinder rolled to the bottom of the ramp. We reasoned that this modification should have the effect of *reversing* the pattern of responses observed in Experiment 1. The infants in the contact condition should be surprised that the bug remained stationary when hit by the cylinder; the infants in the no-contact condition, in contrast, should readily accept that the bug remained stationary because the barrier prevented the cylinder from hitting the bug. The infants in the contact condition were thus expected to look reliably longer than those in the no-contact condition – the opposite pattern from that obtained in Experiment 1.

The procedure used in Experiment 2 was similar to that in Experiment 1, with one noteworthy exception. During pilot testing, it soon became apparent that the new test event was less interesting to the infants than that in Experiment 1 (no doubt because the bug now remained stationary). With repetitions of the event, the infants rapidly became bored, resulting in equal looking times across conditions. To circumvent this difficulty, we decided to present the test event only once per trial rather than repeating it continuously until the end of the trial as in Experiment 1. After the cylinder rolled to the bottom of the ramp, the infants saw the same static scene (the hand resting at the top of the ramp and the cylinder and bug partly visible on either side of the screen) until the trial ended.

Experiment 2

Method

Participants

Participants were 16 healthy term infants ranging in age from 7 months 5 days to 7 months 27 days (M = 7 months 15 days). Half of the infants were assigned to the contact condition (M = 7 months 16 days), and half to the no-contact condition (M = 7 months 14 days). There were three females and five males in the contact condition and equal numbers of males and females in the no-contact condition. An additional four infants were tested but eliminated, two because of procedural problems and two because of observer errors.

Apparatus and stimuli

The apparatus and stimuli used in Experiment 2 were identical to those in Experiment 1 with two exceptions: because the bug remained stationary throughout the test trials, the electric system used to propel the bug and the cream-colored hand used to reposition the bug were not required. As in Experiment 1, the half-barrier was used during the test trials in both the contact and no-contact conditions, to equate auditory cues.

Events

The familiarization displays shown in the contact and no-contact conditions of Experiment 2 were identical to those in Experiment 1. The test event shown in Experiment 2 was also identical to that in Experiment 1, up to the point in the first event cycle when the cylinder rolled to the bottom of the ramp and hit the bug and posts behind the screen. At this point, the test event shown in Experiment 2 diverged from that in Experiment 1 in two respects. First, the bug remained stationary at the bottom of the ramp. Second, the event was not repeated: the infants saw the same static scene until the trial ended.

Procedure

The procedure used in Experiment 2 was identical to that in Experiment 1 with one exception: because the infants saw the test event only once per test trial, different criteria were used to determine the end of the trials. Each test trial ended when the infant (a) looked away from the event for one consecutive second after having looked at it for at least five cumulative seconds, or (b) looked at the event for 60 cumulative seconds without looking away for one consecutive second. Inter-observer agreement averaged 93% per trial per infant. Preliminary analyses revealed no significant effect of sex on the looking times of the infants in the no-contact and contact conditions at the test event (all $F < 2.35$, all $p > 0.10$); the data were therefore collapsed across sex in subsequent analyses.

Results and discussion

Familiarization trials

The infants' looking times during the familiarization trials (see Figure 3) were analyzed as in Experiment 1. The main effect of condition was not significant, $F(1, 14) = 0.43$, nor was the condition × trial interaction, $F(1, 14) = 0.12$, suggesting that the infants in the contact and no-contact conditions did not differ reliably in their responses to the familiarization displays.

Test trials

The infants' looking times during the test trials (see Figure 3) were analyzed as in Experiment 1. The analysis yielded a significant main effect of condition,

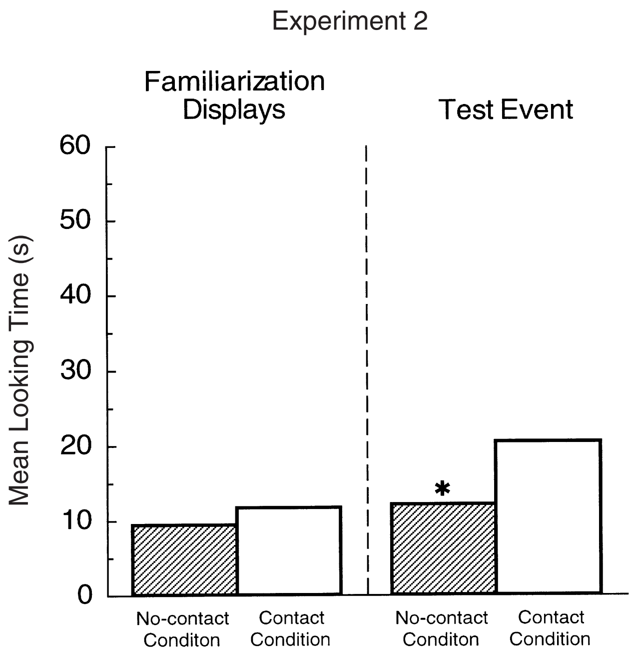

Figure 3 *Mean looking times of the infants in the no-contact and contact conditions of Experiment 2 at the familiarization displays and test event.*

$F(1, 14) = 5.64$, $p < 0.05$, indicating that the infants in the contact condition ($M = 20.5$, SD = 13.2) looked reliably longer at the test event than did those in the no-contact condition ($M = 12.1$, SD = 6.2). No other effects were significant (all $F < 0.60$).

The results of Experiment 2 suggest that the infants (a) expected the bug to move when contacted by the cylinder and to remain stationary otherwise; (b) realized that the cylinder could contact the bug when the half-barrier but not the barrier was present; (c) remembered whether contact was possible between the cylinder and bug after the screen was raised; and hence (d) were surprised in the contact but not the no-contact condition when the bug remained stationary after the cylinder rolled to the bottom of the ramp.

These findings thus confirm those of Experiment 1. First, the results of Experiment 2 provide further evidence that, by 7.5 months of age, infants realize that an inert object cannot displace another inert object without contacting it. The no-contact infants in Experiment 1 were surprised when shown an event *inconsistent* with this expectation (the cylinder did not hit the bug, because of the barrier, and yet the bug still moved); in contrast, the no-contact infants in Experiment 2 gave no indication of being surprised when shown an event *consistent* with this expectation (the cylinder did not hit the bug, and the bug remained stationary). Second, the results of Experiment 2 provide additional evidence that 7.5-month-old infants' differential responses to no-contact and contact events cannot be attributed to low-level perceptual differences between the events. Although the infants in Experiment 2 all saw exactly the same test event, they responded to it differently based on their knowledge – gained in the familiarization trials – of whether contact could or could not occur between the cylinder and bug.

General discussion

The present research was designed to address the following question: do 7.5-month-old infants realize that an object cannot displace another object without contacting it? The results of Experiments 1 and 2 indicate that the answer to this question is positive. Across the two experiments, the infants who believed that the cylinder could *not* contact the bug were surprised when it rolled down the track (Experiment 1) but not when it remained stationary at the bottom of the ramp (Experiment 2). In contrast, the infants who believed that the cylinder *could* collide with the bug were surprised when it remained stationary (Experiment 2) but not when it was launched down the track (Experiment 1).

The present findings are consistent with those of previous experiments (e.g. Leslie, 1982, 1984; Oakes & Cohen, 1990, 1991; Oakes, 1994). The test data obtained in these experiments indicate that infants assume that an object causes another object to move when their motions are spatially and temporally contiguous but not when they are separated by a gap. Such results provide evidence that infants realize that objects cannot set other objects in motion without contacting them. The present results provide additional evidence for this conclusion.

In addition, the present research supports our analysis in the introduction of the habituation data obtained in these same previous experiments (e.g. Leslie, 1982, 1984; Oakes & Cohen, 1990, 1991; Oakes, 1994). Recall that infants were found to look about equally during habituation whether they were shown a no-contact or a contact event. We speculated that these negative results stemmed from the fact that self-moving objects were used in the events: the first object always initiated its motion toward the second object, and both objects typically moved at a constant speed. We proposed that infants realized that the objects before them were self-moving objects and hence were able in each event to produce an explanation for the second object's motion: they assumed that this motion was caused by the first object in the contact event, and by the second object itself in the no-contact event. This analysis predicted that infants should perform differently when shown a no-contact and a contact event involving inert rather than self-moving objects. Infants should now view the no-contact event as surprising or unexpected, and they should therefore look reliably longer at it than at the contact event. This prediction was confirmed by the results of Experiments 1 and 2. The present research thus gives weight to the notion that infants aged 7.5 months and older distinguish between, and hold somewhat different expectations for, inert and self-moving inanimate objects.

The notion that infants distinguish between inert and self-moving objects suggests many interesting directions for future research. In what follows, we consider two of these questions: first, what is the precise nature of this distinction? And second, what information do infants use to determine whether an object is inert or self-moving? Each question is considered briefly in turn.

Distinction between inert and self-moving objects

Our research on infants' acquisition of physical knowledge has led us to propose that infants are born with a highly constrained mechanism responsible for a number of learning processes (e.g. Baillargeon, 1994; 1995; 1998; Baillargeon, Kotovsky & Needham, 1995). One such process is the formation of event categories that correspond to distinct ways in which objects interact; examples of such categories include collision, occlusion, support, containment and arrested-motion events. A second learning process is the identification, separately for each event category, of a sequence of variables that enables infants to predict and interpret outcomes more and more accurately over time. Our assumption is that, just as infants form broad event categories and learn gradually how each category operates, they also form broad object categories and learn gradually what behaviors may be expected of objects from each category in collision, occlusion, support and other events.[5]

The best approach for establishing what different expectations infants hold for inert and self-moving objects, we believe, may be to pit the two types of objects against each other within a single experimental paradigm. Only tentative conclusions can be drawn from comparing results obtained with two or more paradigms because extraneous differences are not controlled for. Experiment 1 of the present research and previous experiments (e.g. Leslie, 1982, 1984; Oakes & Cohen, 1990, 1991; Oakes, 1994) differed not only in their use of inert and self-moving objects, but in many other respects as well. Hence, there remains a possibility that the infants in Experiment 1 responded with prolonged attention to the no-contact event they were shown, not because it involved inert objects, as we have argued, but because of some other feature of the event.[6]

To circumvent these difficulties, we have begun a series of experiments in which the same object is presented as either inert or self-moving (Kaufman, 1997; Kaufman & Baillargeon, 2000; Luo & Baillargeon, 2000). To illustrate, one experiment examined whether 5-month-old infants believe that self-moving but not inert objects can spontaneously reverse their trajectories (Kaufman, 1997). The infants were assigned to an inert or a self-moving condition. The infants in the inert condition first received familiarization trials in which they saw a hand hit a small red box which then moved to the right and disappeared behind the left edge of a large screen. After a few seconds, the box reappeared from behind the left edge of the screen and returned to its starting position near the hand. Following familiarization, the large screen was removed, and the infants saw two test events. In one (near-wall event), the hand again hit the box, which then traveled to the right, hit a wall partition 42 cm wide that filled the right end of the apparatus, and then (as though bouncing back) returned to its starting position. In the other event (far-wall event), the box reversed its trajectory in the same exact location but this time spontaneously, because the wall partition was only 18 cm wide so that the box never reached it. The infants in the self-moving condition saw the same familiarization and test events as the infants in

[5] Over the past 15 years, numerous investigations of infants' physical knowledge have made use of self-moving objects such as screens (e.g. Baillargeon *et al*., 1985), toy carrots (e.g. Baillargeon & DeVos, 1991), rectangles (e.g. Arterberry, 1993), cylinders (e.g. Spelke, Kestenbaum, Simons & Wein, 1995), balls and boxes (e.g. Wilcox & Baillargeon, 1998), and so on. The results of these experiments indicate that, in many contexts, infants hold similar expectations for inert and self-moving objects. For example, infants realize that objects from both categories (a) exist and move continuously when behind occluders and (b) cannot pass through other objects or surfaces. The focus of the present discussion, however, is on whether there are some contexts in which infants hold different expectations for inert and self-moving objects, and on what these differences tell us about infants' conceptualization of the two object categories.

[6] A number of researchers (e.g. Ball, 1973; Oakes, 1991; Woodward, Phillips & Spelke, 1993; Van de Walle, Woodward & Phillips, 1994) have reported that, when shown an occluded contact event involving self-moving objects (e.g. an object moves behind one end of a screen and, after an appropriate interval, another object emerges from behind the other end of the screen), infants assume that the first object hit the second object behind the screen. To our knowledge, there is no evidence of how infants would respond if they were first shown, as in the no-contact condition of Experiment 1, that a barrier prevented contact between the two objects behind the screen. Would infants be surprised by the event, as in Experiment 1, or would they simply conclude that the second object caused its own motion? Evidence that infants were *not* surprised would provide further support for the proposal that infants respond differently to events involving inert and self-moving objects.

the inert condition, except that the box initiated its own motion; the hand lay flat on the apparatus floor throughout the events.

During the familiarization trials, the infants in the inert and self-moving conditions tended to look equally at the event they were shown. During the test trials, the infants in the inert condition looked reliably longer at the far- than at the near-wall event, whereas those in the self-moving condition looked about equally, and equally low, at the two events. These and control results suggest that the infants (a) categorized the box as inert or self-moving based on how its motion was initiated and (b) were surprised to see the inert but not the self-moving box reverse its trajectory.

An ongoing experiment (Luo & Baillargeon, 2000) builds on the results of Experiment 2 and asks whether 6-month-old infants expect an inert but not a self-moving object to be displaced when hit (recall that the infants in the contact condition of Experiment 2 were surprised that the inert bug failed to be displaced when hit). The infants are assigned to an inert or a self-moving condition. The infants in the inert condition sit in front of a large screen. During familiarization, a red box emerges from the right edge of the screen, travels to the right until it hits a wall partition, and then (as though bouncing back) returns behind the screen. The infants in the self-moving condition see a similar event except that the box reverses spontaneously: the wall partition is much smaller so that the box never reaches it. Following familiarization, the screen is removed, and the infants in the two conditions see the same test event: a hand hits the box, which remains stationary.

The results obtained to date suggest that the infants in the inert and self-moving conditions tend to look equally during the familiarization but not the test trials: the infants in the inert condition look reliably longer than do those in the self-moving condition. These results suggest that the infants (a) categorize the box as inert or self-moving based on how its reversal is effected and (b) expect the inert but not the self-moving box to move when hit.

Additional experiments are planned to uncover what further differential expectations infants hold for inert and self-moving objects in collision, support, occlusion and other physical events. Beyond these descriptive forays, it will be essential to address at least two central questions. First, how should infants' expectations about inert and self-moving objects be characterized? Do infants simply form lists of what behaviors may be expected from objects in each category? Or does some underlying core bind together and give causal meaning to the behaviors identified for each object category? Leslie (1994, 1995) has proposed that infants are born with a primitive notion of force that informs from the start their representations of objects and events. Following Leslie, we have speculated (e.g. Baillargeon, 1998; Kotovsky & Baillargeon, 1998) that, whereas some of the event categories infants identify are defined purely in spatiotemporal terms (e.g. occlusion events in which an object passes behind a nearer object), other event categories involve both spatiotemporal and mechanical relations (e.g. collision events in which a first object approaches and hits a second object). Extending these speculations to the present discussion, we might suggest that infants' object categories also involve mechanical information, and that the distinction between inert and self-moving objects is really a distinction between objects with and without internal forces. Objects *without* internal forces would move only when acted upon, and would be limited to receiving and transmitting forces. In contrast, objects *with* internal forces would move on their own, and would be capable not only of receiving and transmitting forces but also of exerting and resisting forces (if infants are not surprised to see a self-moving box remain stationary when hit by a hand, it may be because they view the box as capable of resisting the force exerted by the hand; Luo & Baillargeon, 2000).

A second central question to be answered in future research concerns the distinction between self-moving and animate objects. Throughout this paper, we have held fast to the view that, in the course of observing the world around them, infants come to distinguish between self-moving and inert inanimate objects and learn gradually what behaviors may be expected of objects from each category. This view presupposes that infants also draw a distinction between animate and inanimate objects, with animate objects (e.g. people, dogs, fish) being capable of a wider range of behaviors than are self-moving and inert inanimate objects. In this approach, animate objects would be those that present certain facial features, self-deform as they move, are capable of emotion, perception, intention and learning, and so on (e.g. Gelman & Spelke, 1981; Poulin-Dubois, 1999). The view adopted here could, of course, be incorrect: it might be that at the ages studied here infants draw not *two* distinctions – those between animate and inanimate objects, and between inert and self-moving inanimate objects – but only *one* distinction – that between animate/self-moving and inert objects. To decide which of these views is correct, one might examine, as a first step, whether infants are surprised when they see a self-moving object – such as the red box used by Kaufman (1997) and Luo and Baillargeon (2000) – exhibit behaviors characteristic of animate objects. Positive findings would strengthen the view that infants distinguish between animate and self-moving objects; negative results, on the other hand, would suggest that infants distinguish only between animate/self-moving and inert objects.[7]

How do infants determine whether an object is inert or self-moving?

Implicit in the previous discussion are a number of assumptions about how infants determine whether a new inanimate object they encounter is inert or self-moving. First, we assume that infants view objects as inert unless confronted with clear and unambiguous evidence that they are not. Second, such evidence may involve seeing an object exhibit one or more of the behaviors that have been identified as characteristic of self-moving objects; e.g. seeing an object initiate its own motion (e.g. Leslie, 1982; Oakes, 1994; Kaufman, 1997) or spontaneously reverse course (e.g. Luo & Baillargeon, 2000). Third, we assume that infants may categorize an object as self-moving without seeing it exhibit a behavior typical of self-moving objects, if it is perceptually similar to another object that has already been categorized as self-moving.

The three assumptions listed above are sufficient to explain why the infants in previous experiments (e.g. Leslie, 1982, 1984; Leslie & Keeble, 1987; Oakes & Cohen, 1990, 1991; Oakes, 1994) saw the two objects they were shown as self-moving: the first object always initiated its own motion and was perceptually similar to the second object (the two objects typically differed only in color). The assumptions above are also sufficient to explain why the infants in the self-moving conditions of Kaufman (1997) and Luo and Baillargeon (2000) saw the box as self-moving: from the start, the box either initiated its own motion (Kaufman, 1997) or spontaneously reversed course (Luo & Baillargeon, 2000).

However, the assumptions above are not quite sufficient to explain why the infants in the present research and in the inert conditions of Kaufman (1997) and Luo and Baillargeon (2000) viewed the toy bug or box they were shown as an inert object. Consider the case of Experiment 1. The infants in the no-contact condition saw the bug stationary in two familiarization trials, and then they saw the bug being displaced in six test trials. We suppose that the infants viewed the bug as inert during the familiarization trials because at that point they lacked any information to the contrary. But what of the test trials? Why did the infants not revise their categorization of the bug upon seeing that it could move when not hit, and conclude that it must after all be self-moving? The fact that the infants responded with prolonged attention throughout all six test trials suggests that they kept on being puzzled that the inert bug before them should move when not hit. Similar questions can be raised about the responses of the infants in the contact condition of Experiment 2 (why did the infants not conclude, upon seeing that the bug remained stationary when hit, that it was self-moving and capable of resisting the cylinder's impact?) and of the infants in the inert conditions of Kaufman (1997) and Luo and Baillargeon (2000) (why did the infants not conclude, upon seeing that the box could reverse course on its own or resist the hand's impact, that it must after all be self-moving?).

We believe that a fourth assumption is needed to account for these results. This assumption is that, when infants are first exposed to a novel object, there is a narrow time window during which they sample the object's behavior and decide on a category assignment. Once made, this assignment is not easily revised. Thus, according to this assumption, self-moving behaviors observed in an object *during and after* the category assignment window would all be perceived as readily explainable: infants would conclude, based on the evidence available during the window, that the object is self-moving, and they would interpret its subsequent behaviors as consistent with its category. In contrast, self-moving behaviors observed in an object only *after* the category assignment window would be perceived as unexpected: infants would conclude, based on the evidence available during the window, that the object is inert, and so they would be perplexed by its subsequent, inconsistent behavior.

The preceding discussion suggests several interesting directions for future research. One such direction concerns the range of behaviors that infants will take as evidence that an object is self-moving. Seeing an object spontaneously move or reverse course would seem to constitute excellent evidence that it is self-moving under most circumstances, but what of seeing an object *not* move when hit? Adults realize that objects may not move for several reasons: because they are heavy, because they are affixed to their surroundings, and so on. At what age do infants become aware of these

[7] A current controversy in the animacy literature concerns infants' notion of intentionality. According to some researchers (e.g. Premack, 1990; Baron-Cohen, 1997), infants view all self-propelled motions as intentional or goal-directed. According to other researchers (e.g. Mandler, 1992; Gergely, Nádasdy, Csibra & Bíró, 1995; Woodward, 1998, 1999), additional criteria must be met for infants to view self-propelled motions as intentional – though there is disagreement as to what these additional criteria might be. Experiments are planned to examine whether infants perceive the displacements of the self-moving box used by Kaufman (1997) and Luo and Baillargeon (2000) as intentional or not, and what the consequences of either perception are for infants' predictions and interpretations of the box's future behavior.

complexities? A second direction has to do with infants' revision of incorrect object category assignments. What conditions facilitate this process? Would seeing an inert object engage in multiple self-moving behaviors (as opposed to just one) hasten the revision process?

Concluding remarks

The present research confirms previous findings that, by 7.5 months of age, infants realize that an object cannot set another object in motion without contacting it (e.g. Leslie, 1982, 1984; Oakes & Cohen, 1990, 1991; Oakes, 1994). In addition, the present results support the proposal that, in the course of observing the world around them, infants come to distinguish between inert and self-moving inanimate objects and develop somewhat different expectations for these two object categories. In particular, infants appear to be surprised by no-contact events involving inert but not self-moving objects.

In the General Discussion, we raised several issues concerning the nature of the distinction infants draw between inert and self-moving objects. This discussion makes clear that a great deal of research will be needed to determine (a) what criteria infants use to judge whether objects are inert or self-moving, and how these criteria change with age; (b) what expectations infants hold about inert and self-moving objects in different physical events, and how these expectations develop over time; (c) whether Leslie's (1994, 1995) force model provides the best account of the distinction infants perceive between inert and self-moving (or, to borrow Leslie's term, mechanical) objects; and finally (d) whether infants distinguish between animate and mechanical objects, or view all of these – at least initially – as belonging to a single broad category.

Finding the answers to these questions should be exciting, both because of what they tell us about the development of infants' knowledge about objects, and also because of what they reveal about the learning mechanism that guides infants' acquisition of physical knowledge. We are particularly struck by the fact that different portions of our research program are converging on the same key notion of categorization. As was mentioned earlier, there is now evidence that infants form distinct *event* categories (e.g. Wilcox & Baillargeon, 1998; Hespos & Baillargeon, 2000; Aguiar & Baillargeon, 2000; for discussion, see Baillargeon, 1998). In this paper, we have proposed that infants also form distinct *object* categories. Finding out how infants form and use their event and object categories should yield important insights into the nature and operation of their learning mechanism.

Regardless of what characterization is eventually adopted to describe infants' expectations about events and objects, one final contribution of the present research may be worth emphasizing. In many investigations of infants' physical knowledge, conclusions about expectations have been based on infants' differential responses to *distinct* events (e.g. Baillargeon & Graber, 1987; Baillargeon, 1991; Baillargeon & DeVos, 1991; Spelke *et al.*, 1992; Needham & Baillargeon, 1993; Kotovsky & Baillargeon, 1994). This approach has given rise to a concern that, despite researchers' best efforts to include adequate controls, low-level perceptual processes attuned to superficial differences between the events might be responsible for infants' differential responses (e.g. Bogartz, Shinskey & Speaker, 1997; Haith & Benson, 1997). From this perspective, one contribution of the present research is that it found differential responses to *identical* events, based on prior information about the events. Furthermore, this prior information was rather minimal: the infants simply saw a static display depicting the bug and cylinder resting against opposite sides of the barrier, or resting against each other under the half-barrier. It is difficult to conceive of a low-level perceptual process that would explain why, when the lower portion of the barrier or half-barrier was occluded and the cylinder rolled down the ramp, (a) the infants who had seen the barrier display looked reliably longer than those who had seen the half-barrier display if the bug was displaced, but (b) the reverse was true if the bug remained stationary.

Infants' physical world is undeniably more primitive than that of older children and adults, as is made abundantly clear by recent demonstrations of significant developments in the first year of life (for recent reviews, see Spelke *et al.*, 1992; Oakes & Cohen, 1995; Mandler, 1997; Baillargeon, 1998). Nevertheless, from the start, infants' responses to the physical world seem to be determined less by a low-level analysis of what is directly before them and more by abstract rule-governed expectations about objects and events (Baillargeon, 1999).

Acknowledgements

This research was supported by a grant from the National Institute of Child Health and Human Development (HD-21104) to the second author. We thank Jerry DeJong, Cindy Fisher, Yuyan Luo and Kris Onishi for helpful comments; Alison Hauser and Anne Hillstrom for their help with the data analyses; and Andréa Aguiar, Laura Brueckner, Beth Cullum, Myra Gillespie, Lisa Kaufman, Valerie Kolstad, Amy Needham, Helen Raschke, Teresa

Wilcox, and the undergraduate students working in the Infant Cognition Laboratory at the University of Illinois for their help with the data collection. We also thank the parents who kindly agreed to have their infants participate in the experiments.

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Received: 7 July 1997
Accepted: 9 December 1999