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Young infants' reasoning about physical events involving inert and self-propelled objects

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The present research examined whether 5- to 6.5-month-old infants would hold different expectations about various physical events involving a box after receiving evidence that it was either inert or self-propelled. Infants were surprised if the inert but not the self-propelled box: reversed direction spontaneously (Experiment 1); remained stationary when hit or pulled (Experiments 3 and 3A); remained stable when released in midair or with inadequate support from a platform (Experiment 4); or disappeared when briefly hidden by one of two adjacent screens (the second screen provided the self-propelled box with an alternative hiding place; Experiment 5). On the other hand, infants were surprised if the inert or the self-propelled box appeared to pass through an obstacle (Experiment 2) or disappeared when briefly hidden by a single screen (Experiment 5). The present results indicate that infants as young as 5 months of age distinguish between inert and self-propelled objects and hold different expectations for physical events involving these objects, even when incidental differences between the objects are controlled. These findings are consistent with the proposal by Gelman, R. (1990). First principles organize attention to and learning about relevant data: Number and the animate–inanimate distinction as examples. *Cognitive Science, 14*, 79–106, Leslie, A. M. (1994). ToMM, ToBY, and Agency: Core architecture and domain specificity. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 119–148). New York: Cambridge University Press, and others that infants endow self-propelled objects with an internal source of energy. Possible links between infants' concepts of self-propelled object, agent, and animal are also discussed.

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1. Introduction

Investigations of early physical reasoning over the past 20 years have revealed that, by 6 months of age, infants already possess rich expectations about physical events (e.g., Aguiar & Baillargeon, 2002; Baillargeon & DeVos, 1991; Baillargeon, Spelke, & Wasserman, 1985; Durand & Lécuyer, 2002; Goubet & Clifton, 1998; Hespos & Baillargeon, 2001b; Hespos & Baillargeon, 2008; Hofstadter & Reznick, 1996; Hood & Willatts, 1986; Kochukhova & Gredebäck, 2007; Kotovsky & Baillargeon, 1998; Lécuyer & Durand, 1998; Leslie, 1984a; Leslie & Keeble, 1987; Luo & Baillargeon, 2005b; Luo, Baillargeon, Brueckner, & Munakata, 2003; Needham & Baillargeon, 1993; Ruffman, Slade, & Redman, 2005; Sitskoorn & Smitsman, 1995; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Spelke, Kestenbaum, Simons, & Wein, 1995; von Hofsten, Kochukova, & Rosander, 2007; Wang, Baillargeon, & Brueckner, 2004; Wang, Baillargeon, & Paterson, 2005; Wilcox, 1999; Wilcox, Nadel, & Rosser, 1996). Some of these experiments used inert objects (e.g., inert balls, boxes, cylinders, toy bugs, toy cars or toy lions), whereas others used self-propelled objects (e.g., self-propelled balls, boxes, cylinders, toy bears, toy carrots or toy mice). The choice of inert or self-propelled objects was typically made for reasons of methodological convenience and had little effect on the results. For example, investigations focusing on occlusion events found that infants aged 3.5 months and older expect an object, whether inert or self-propelled, (1) to continue to exist when behind an occluder; (2) to follow a continuous, unobstructed path when behind an occluder; and (3) to remain partly visible when taller or wider than the occluder (e.g., Baillargeon, 1986; Baillargeon, 1987; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Hespos & Baillargeon, 2001a; Hespos & Baillargeon, 2006; Hofstadter & Reznick, 1996; Kochukhova & Gredebäck, 2007; Luo & Baillargeon, 2005b; Luo et al., 2003; Ruffman et al., 2005; Spelke et al., 1992; von Hofsten et al., 2007; Wang et al., 2004; Wilcox, 1999; Wilcox et al., 1996; for a possible exception we return to later on, see Kuhlmeier, Bloom, & Wynn, 2004).

On the basis of such results, we might be tempted to conclude that young infants' expectations about physical events are framed in terms of a single category of objects, namely, physical objects. Such a conclusion would be premature, however, for the following reasons. First, many investigations of infants' physical reasoning to date have focused on physical events where even adults would hold similar expectations for inert and self-propelled objects. Second, when experiments have involved physical events where different expectations could conceivably have arisen for inert and self-propelled objects, no such comparison was performed (or indeed required), because it fell outside of the investigators' expressed research agenda.

An important exception to this last generalization comes from work by Kosugi, Saxe, Woodward, and their colleagues (e.g., Kosugi & Fujita, 2002; Kosugi, Ishida, & Fujita, 2003; Saxe, Tenenbaum, & Carey, 2005; Saxe, Tzelnic, & Carey, 2007; Spelke, Phillips, & Woodward, 1995; Woodward, Phillips, & Spelke, 1993). This research examined whether infants aged 7 months and older recognize that (1) a self-propelled object can initiate its own motion, whereas an inert object cannot, and (2) an inert object can be set into motion only through contact with (and the application of force by) another object. In one experiment, for example, 7-month-old infants were assigned to an inert or a self-propelled condition (Woodward et al., 1993; see also Spelke, Phillips, et al., 1995). The infants in the inert condition were habituated to a videotaped event involving two large (human-sized) wheeled blocks that differed in height, width, shape, pattern, and color. To start, one block moved into view on the left side of the television monitor and disappeared behind the left edge of a large occluder at the center of the monitor; the second block was partly visible at the right edge of the occluder. After an appropriate interval, the second block moved to the right and disappeared on the right side of the monitor. The entire event sequence was then repeated in reverse. Following habituation, the occluder was removed, and the infants saw two test events in which the blocks moved as before; the only difference between the events had to do with what happened during the previously occluded portion of the blocks' trajectories. In one event (contact event), the moving block collided with the stationary block and set it into motion; in the other event (no-contact event), the moving block stopped short of the stationary block, which then set off on its own. The infants in the self-propelled condition saw identical events except that the two blocks were replaced with a man and a woman who walked along the same path as the blocks.

The infants in the inert condition looked reliably longer at the no-contact than at the contact event, whereas those in the self-propelled condition looked about equally at the two events. These and control results suggested three conclusions. First, because there was no clear indication that the blocks were self-propelled during the habituation trials (it was unclear what caused them to roll into view on either side of the television monitor), the infants categorized them as inert; infants thus appear to hold the default assumption that a novel object is inert unless given unambiguous evidence that it is self-propelled (see also Luo & Baillargeon, 2005a). Second, the infants understood that inert objects can be set into motion only through contact with (and the application of force by) other objects, and thus they inferred that one block must be colliding with the other block behind the occluder. Third, the infants realized that humans are self-propelled objects, which can move at will.[1]

The preceding results suggest that by 7 months of age infants hold different expectations for at least some physical events involving inert and self-propelled objects. Where might these different expectations come from? One hypothesis, put forth by Gelman (1990; Gelman & Spelke, 1981; Gelman, Durgin, & Kaufman, 1995; Subrahmanyam, Gelman, & Lafosse, 2002) and Leslie (1984a, 1994, 1995; Leslie & Keeble, 1987), is that part of the skeletal causal framework infants bring to bear when interpreting physical events is a fundamental distinction between inert and self-propelled objects. When infants watch a novel object begin to move or change direction, their physical-reasoning system attempts to determine whether the change in the object's motion state is caused by forces internal or external to the object. According to Leslie (1994), "the more an object changes motion state by itself and not as a result of external impact, the more evidence it provides, the more likely it is, that it is [self-propelled]" (p. 133). An object that is judged to be self-propelled is endowed with <u>an internal source of energy</u>. A self-propelled object can use its internal energy directly to control its own motion and indirectly (through the application of force) to control the motion of other objects. We refer to this hypothesis as the internal-energy hypothesis, for ease of communication.

If the internal-energy hypothesis is correct, then young infants may hold different expectations for physical events involving inert and self-propelled objects whenever they believe that an application of internal energy can bring about a different outcome. Thus, infants may be surprised to see an inert but <u>not</u> a self-propelled object remain stationary when hit, if they reason that the self-propelled object can use its internal energy to resist efforts to move it. In contrast, infants may be surprised to see an inert <u>or</u> a self-propelled object disappear into thin air, if they realize that no application of internal energy could result in the disappearance of the self-propelled object.[2]

The preceding reasoning led us to undertake an extensive series of experiments to systematically compare 5- to 6.5-month-old infants' responses to various physical events involving an inert or a self-propelled object. To control for extraneous factors, the inert and the self-propelled object used in the experiments was the <u>same</u> small box. During familiarization, half the infants were given evidence that the box was self-propelled (e.g., the box initiated its own motion in plain view); the other infants were given no such evidence and so presumably categorized the box as inert. Whether self-propelled or not, the box always moved in exactly the same manner: its motion was actually controlled by a mechanical device, to ensure uniformity across trials and conditions. During test, the infants saw various physical

[1] Kosugi and Fujita (2002) tested 8-month-old infants using a procedure similar to that of the inert condition in Woodward et al. (1993; Spelke, Phillips, et al., 1995), but they obtained negative results. However, the experiment of Kosugi and Fujita differed from that of Woodward in several key respects. In particular, the first block (instead of moving into view) stood on the left side of the television monitor and began to move on its own; in addition, the two blocks (instead of differing in height, width, shape, pattern, and color) differed mainly in color and width. Thus, one interpretation of the results is that (1) the infants viewed the first block as self-propelled; (2) because the second block was perceptually similar to the first block, the infants assumed that it, too, was self-propelled; and (3) since both blocks were self-propelled, the infants found neither the contact nor the no-contact event surprising (as in the self-propelled condition of Woodward et al.). In another experiment, Kosugi and Fujita replaced the first block with a human; the infants who saw the no-contact event now looked reliably longer than those who saw the contact event, suggesting that they viewed the block as an inert object and understood that it could be set in motion only through contact. These results, together with those of Woodward et al., suggest that infants view an object as inert unless given unambiguous evidence that it, or an object that is perceptually similar to it, is self-propelled.

[2] Two caveats may he helpful at this point. First, the operation of the physical-reasoning system is assumed to be largely unconscious: infants are not aware of the causal framework they use when reasoning about physical events, any more than young children are aware of the grammar of their language as they begin to understand and produce sentences. Thus, when we say that infants "reason", "believe", "judge", "realize", and so on, we do so only for ease of communication; infants' reasoning is assumed to be carried out without explicit awareness. Second, infants are said to be surprised in violation-of-expectation tasks when they look reliably longer at events that violate, as opposed to confirm, their expectations; the term surprised is thus used here simply as a short-hand descriptor, to denote a state of heightened attention or interest induced by an expectation violation.

events involving the box. The experiments tested whether infants (1) would view the outcomes of some events as surprising when they categorized the box as inert but not as self-propelled, because in the latter case they could infer that the box had used its internal energy to bring about the observed outcomes; and (2) would view the outcomes of other events as surprising whether they categorized the box as inert or as self-propelled, because they realized that no application of internal energy could explain the observed outcomes.

We speculated that evidence that infants hold different expectations for some but not other physical events involving inert and self-propelled objects, under these controlled conditions, would be important for three reasons. First, it would provide strong evidence that infants' expectations about physical events are framed in terms of not one but two categories of objects: inert and self-propelled objects. Second, it would support the internal-energy hypothesis proposed by Gelman and Leslie (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995). Finally, it would lead to interesting questions about possible links between the concept of self-propelled object in the present research (see also Baillargeon, Wu, Yuan, Li, & Luo, in press), the concept of agent in the psychological-reasoning literature (e.g., Csibra, 2008; Johnson, Shimizu, & Ok, 2007; Johnson et al., 2008; Luo & Baillargeon, 2005a), and the concept of animal in the conceptual-development literature (e.g., Carey, 1985; Gottfried & Gelman, 2005; Mandler, in press; Subrahmanyam et al., 2002). We return to these issues in the Section 7.

2. Experiment 1: can an inert or a self-propelled object spontaneously reverse direction?

We have seen that infants hold different expectations for the onset of inert and self-propelled objects' (horizontal) displacements: they realize that a self-propelled object can initiate its own motion, whereas an inert object cannot (e.g., Kosugi & Fujita, 2002; Kosugi et al., 2003; Saxe et al., 2005; Saxe et al., 2007; Spelke, Phillips, et al., 1995; Woodward et al., 1993). Do infants also hold different expectations for the path inert and self-propelled objects are likely to follow once in motion? As adults, we recognize that a self-propelled object can use its internal energy to change direction at will; in contrast, we expect an inert object to follow a smooth path, without abrupt changes in direction. Thus, we would be surprised if a ball rolling on a table changed direction as it reached each corner so as to follow the perimeter of the table; with inert objects, abrupt changes in direction cannot be achieved without external impact.[3] In Experiment 1, we asked whether 5-month-old infants would expect an inert but not a self-propelled object to follow a smooth path, with no abrupt change in direction.

Previous research suggested that young infants are not surprised when an inert object abruptly deviates from its initial path. Spelke, Katz, Purcell, Ehrlich, and Breinlinger (1994) habituated 4- and 6-month-old infants to an event in which a ball rested in the front right corner of a large table (here and throughout this article, events are described from the infants' perspective); a horizontal screen hid the left half of the table. An experimenter's hand hit the ball, which then rolled diagonally across the table until it disappeared under the screen at the center of the table. Next, the screen was removed to reveal the ball resting in the back left corner of the table, further along its pre-occlusion trajectory. Following habituation, the infants saw a linear and a non-linear test event. The linear event was similar to the habituation event except that the ball started from the back right corner of the table; it rolled diagonally across the table until it disappeared under the screen and was revealed resting in the front left corner of the table, as expected. In the non-linear event, the ball again started from the back right corner of the table and rolled diagonally across the table; however, when the screen

[3] The expectation that an inert object will travel on a smooth path, with no abrupt change in direction, is consistent with, though considerably weaker than, the Newtonian principle of inertia. According to this principle, "if no external forces act on a body, it moves uniformly, that is, always with the same velocity along a straight line" (Einstein & Infeld, 1960, p. 8). In everyday life, however, uniform motion can "never be realized; a stone thrown from a tower, a cart pushed along road can never move absolutely uniformly because we cannot eliminate the influence of external forces" (Einstein & Infeld, 1960, p. 8). Not surprisingly, since the principle of inertia is derived from scientific reasoning rather than from immediate observation, it was not understood for many centuries, until the discoveries of Galileo and Newton, and it plays little role in adults' everyday physical reasoning (e.g., Einstein & Infeld, 1960; McCloskey, 1983; Spelke et al., 1994).

was removed, the ball rested in the same back left corner as in the habituation event, as though it had performed a 90° turn when under the screen. The infants did not look longer at the non-linear than at the linear event, and Spelke and her colleagues concluded that young infants do not expect an inert object, once in motion, to follow a smooth path.

However, other interpretations of these negative results were possible. Because of limitations in the apparatus used to implement the experimental design, the infants were actually presented with a more subtle violation than is suggested by the preceding description. In reality, most of the left side of the table was filled with a large insert with a central indentation in its right edge; the ball came to rest in the front or back corner of this indentation. Thus, rather than seeing the ball at rest in the front or back left corner of the table at the end of the test events (a large and salient difference), the infants saw the ball at rest in the front or back corner of the indentation (a smaller and perhaps less salient difference). This arrangement might have made it difficult for the infants to determine whether or how far the ball had deviated from its pre-occlusion trajectory. Keeping in mind that young infants might be limited in their ability to represent trajectories, we presented the infants in Experiment 1 with a very salient violation: a full reversal, in plain view.

The infants were assigned to an inert or a self-propelled condition (see Fig. 1). The infants in the inert condition sat in front of a large apparatus whose right side was occluded by a large screen; a

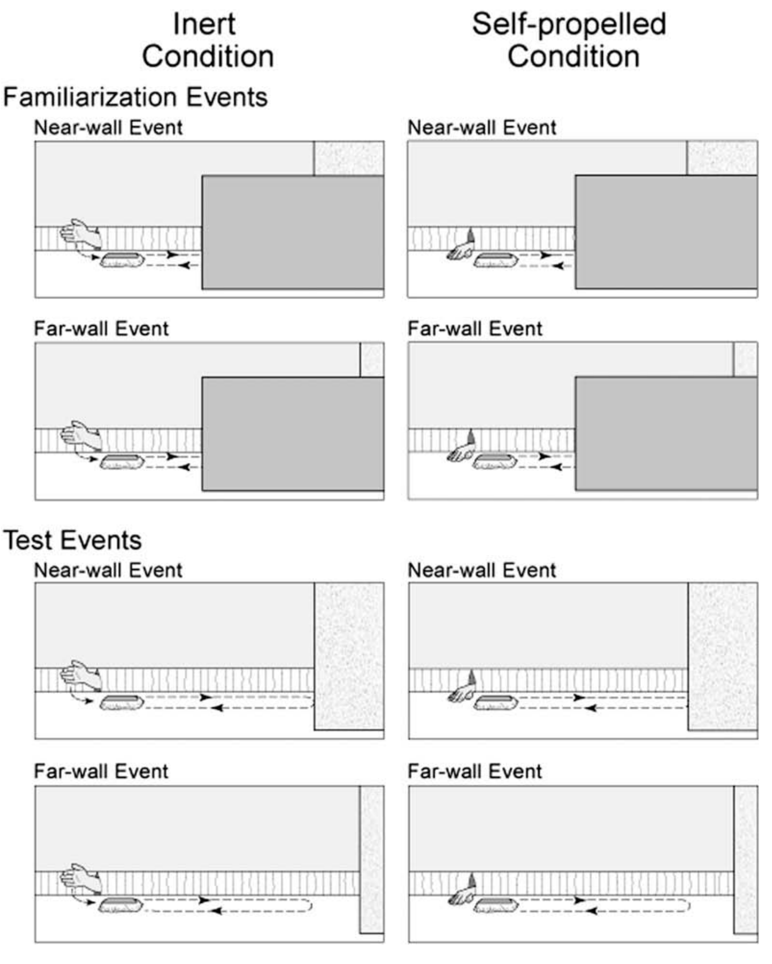

Fig. 1. Schematic drawing of the familiarization and test events in Experiment 1.

small box was visible on the left side of the apparatus. In the familiarization event, an experimenter's gloved hand hit the box, which then moved to the right until it disappeared behind the left edge of the screen. After a few seconds, the box reappeared from behind the same edge of the screen and returned to its starting position. Following familiarization, the screen was removed, and the infants watched two test events. In one, the hand again hit the box, which moved to the right until it hit a wall partition at the right end of the apparatus; the box then reversed direction, as though bouncing back, and returned to its starting position (near-wall event). In the other event, the wall partition was placed farther to the right; because the box moved exactly as before, it now reversed direction on its own, without hitting the wall partition (far-wall event). Since the wall partition changed position in the near- and far-wall test events, it was also placed in the same two positions on alternate familiarization trials; however, because the screen was in place during these trials, only the very top of the wall partition was visible above the screen (see Fig. 1). The infants in the self-propelled condition saw identical near- and far-wall familiarization and test events except that the box initiated its own motion: the hand remained stationary on the apparatus floor.

Our reasoning was as follows. If at 5 months infants tend to view an object as inert unless given unambiguous evidence that it is not (e.g., Luo & Baillargeon, 2005a), then the infants in the inert condition should categorize the box as inert during the familiarization trials because (1) they saw the hand set it in motion, and (2) they had no evidence as to what caused its reversal behind the screen. In contrast, the infants in the self-propelled condition should categorize the box as self-propelled because they saw it initiate its own motion.

Furthermore, if at 5 months infants (1) endow self-propelled but not inert objects with internal energy (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995), and (2) expect an object to follow a smooth path unless a force—either internal or external to the object—intervenes to bring about a change, then the infants in the inert and self-propelled conditions should respond differently to the test events. In the inert condition, the infants should be surprised when the box reversed direction spontaneously but not when it reversed direction after hitting the wall partition; this impact provided an external cause for the abrupt change in the box's trajectory. The infants should thus look reliably longer at the far- than at the near-wall event. In the self-propelled condition, in contrast, the infants should not be surprised when the box reversed direction either spontaneously—it could use its internal energy to do so—or after hitting the wall partition. The infants should thus look about equally at the far- and near-wall events.

2.1. Method

2.1.1. Participants

Participants were 32 healthy term infants, 16 male and 16 female, ranging in age from 4 months, 16 days to 5 months, 10 days (M = 4 months, 28 days, SD = 7.5 days). Another 11 infants were tested but eliminated from the analyses, five because they were distracted (3), fussy (1), or overly active (1), four because of observer difficulties, and two because they looked for the maximum amount of time allowed (60 s) on all four test trials. Half the infants were randomly assigned to the inert condition (eight male and eight female; M = 4 months, 28 days, SD = 7.0 days), and half to the self-propelled condition (M = 4 months, 28 days, SD = 8.3 days).

The infants' names in this and in the following experiments were obtained primarily from purchased mailing lists and from birth announcements in the local newspaper. Parents were contacted by letters and follow-up phone calls; they were offered reimbursement for their transportation expenses but were not compensated for their participation.

2.1.2. Apparatus

The apparatus consisted of a wooden display booth 125 cm high, 164 cm wide, and 78 cm deep that was positioned 76 cm above the room floor. The infant faced an opening 46 cm high and 157.5 cm wide in the front wall of the apparatus; between trials, a curtain consisting of a muslin-covered frame 56.5 cm high and 163 cm wide was lowered in front of this opening. The side walls of the apparatus were painted white and the floor was covered with black contact paper. The back wall was constructed of foam board and was covered with a gray granite-patterned contact paper; at the bottom of the wall, along its entire width, was an opening 15 cm high that was filled with a gray fringe. The experimenter used this opening to introduce her right hand (covered with a golden spandex glove) into the apparatus.

The box used in the experiment was 5 cm high, 19.5 cm wide, and 17 cm deep, made of wood, and covered with red felt. The four sides of the box (all but the top and bottom) were also covered with two layers of white lace; this lace "skirt" reached the apparatus floor and hid the mechanism that allowed the box to move back and forth across the apparatus.

The box moved along a slit 104 cm wide and 2 cm deep in the apparatus floor, located 28.5 cm from the left wall and 35 cm from the back wall. The box was mounted 0.5 cm above the apparatus floor on four small rubber wheels. Two metal plates anchored to the bottom of the box protruded through the slit in the apparatus floor and were attached beneath the floor to the top of a belt loop. At the start of each trial, the box was positioned at the left end of the slit. When the motorized system that drove the belt loop was activated, the top of the belt moved clockwise, carrying the box to the right at a constant speed of about 50 cm/s. After the box travelled for 75 cm (its leading edge was then 123 cm from the left wall), its metal plates hit a reverse-switch under the apparatus floor; this caused the top of the belt to now move counterclockwise, so that the box was carried back to its starting position. The box then stopped until the motorized system was activated once more. In the inert condition, the experimenter's gloved hand activated the motorized system by hitting a microswitch located 0.25 cm to the left of the box and 1.25 cm behind the slit; the microswitch was 2.7 cm high, 0.2 cm wide, and 0.5 cm deep, and was covered with black contact paper. The hand simultaneously hit the microswitch and the box, so that it appeared as though the hand caused the box to move. In the self-propelled condition, the experimenter activated the motorized system by depressing a button on a control panel located under the apparatus floor. The box's movement back and forth across the apparatus was accompanied by noise from the motorized system; this noise was identical in the inert and self-propelled conditions.

During the experiment, a wall partition filled the right end of the apparatus and was fastened in place with Velcro and stabilized with weights. The wall partition was made of foam board, was covered with the same gray granite-patterned contact paper as the back wall of the apparatus, and consisted of two joined surfaces: a side surface, which stood perpendicular to and abutted the back wall of the apparatus; and a front surface, which stood parallel to the back wall, 13 cm from the front edge of the apparatus. The side surface was 73.5 cm high and 65 cm deep. The front surface was also 73.5 cm high and could be folded so that its width (and hence the location of the side surface) varied across events. In the near-wall familiarization and test events, the front surface was 41 cm wide; in this event, the side surface stood 123 cm from the left wall of the apparatus, at the point where the box reversed direction (we will refer to this position of the wall partition as the <u>near position</u>). Although the box appeared to hit the side surface and "bounce back", in actuality only its lace skirt contacted the side surface; the reverse-switch under the apparatus caused the box to reverse direction. In the far-wall familiarization and test events, the front surface was 21 cm wide, so that the side surface now stood 143 cm from the left wall, 20 cm to the right of the point where the box reversed direction (we will refer to this position of the wall partition as the <u>far position</u>).

The screen used during the familiarization trials was 50.5 cm high, 90 cm wide, and 0.5 cm thick; it was made of foam board, covered with green contact paper, and supported at the back by a wooden base. During the familiarization trials, the screen stood parallel to and 9 cm from the front edge of the apparatus, and abutted the right wall of the apparatus. The screen hid the right portion of the box's trajectory as it moved back and forth across the apparatus. It also hid a large portion of the wall partition: only the top 23 cm of the wall partition, in its near or far position, was visible above the screen (see Fig. 1).

The infants were tested in a brightly lit testing room, and two 40-W fluorescent light bulbs attached to the front and back walls of the apparatus provided additional light. Two wooden frames, each 192 cm high, 63.5 cm wide, and covered with gray cloth, stood at an angle on either side of the apparatus; these frames served to isolate the infants from the testing room.

2.1.3. Events

In the following text, the numbers in parentheses indicate the number of seconds taken to perform the actions described. To help the experimenter adhere to the events' scripts, a metronome beat softly once per second.

2.1.3.1. Inert condition. Near-wall familiarization event. At the start of the near-wall familiarization event, the wall partition was in its near position. The box was in its starting position at the left end of the slit; the experimenter's gloved right hand rested palm down on the apparatus floor, 9 cm to the left of the box; and the screen was in place, 26 cm to the right of the box. The hand rotated 90° while swinging back (so the palm now faced the box) (1 s) and then hit the box (and the microswitch, surreptitiously), to initiate the box's motion (1 s). While the hand returned to its starting position, the box moved behind the screen, reversed direction, and emerged from behind the screen to return to its starting position (3 s). After a 1-s pause, the event was repeated. Each event cycle thus lasted about 6 s; cycles were repeated until the computer signaled the end of the trial (see below). When this occurred, a second experimenter lowered the curtain in front of the apparatus.

Far-wall familiarization event. The far-wall familiarization event was identical to the near-wall familiarization event except that the wall partition was in its far position.

Near-wall test event. The near-wall test event was similar to the near-wall familiarization event except that the screen was removed from the apparatus. Therefore, the infants could watch as the box travelled to the right, hit the wall partition, reversed direction (as though bouncing back), and returned to its starting position.

Far-wall test event. The far-wall test event was identical to the near-wall test event except that the wall partition was in its far position, so the box appeared to reverse direction spontaneously.[4]

2.1.3.2. Self-propelled condition. The events shown in the self-propelled condition were identical to those in the inert condition except that the experimenter's hand remained palm down on the apparatus floor, 9 cm to the left of the box in its starting position, throughout the experiment. In each event cycle, after a 1-s pause, the experimenter used her left hand to press the button on the control panel (1 s), out of the infants' view. The box then travelled through the apparatus and returned to its starting position (3 s), followed by a 1-s pause. Each event cycle thus lasted 6 s, as in the inert condition; in addition, the experimenter pressed the button at the point in each cycle where she would have hit the box, so that the timing of the box's movement across the apparatus was similar across the two conditions.

2.1.4. Procedure

During the experiment, the infant sat on a parent's lap in front of the apparatus, facing a point midway between (71.5 cm from) the left wall of the apparatus and the wall partition in its far position; the infant's head was approximately 100 cm from the slit in the apparatus floor. Parents were instructed not to interact with their infant during the experiment; they were also asked to close their eyes during the 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 could not see the events from their viewpoints and they did not know the order in which the test events were presented. Each observer held a button box linked to a computer and pressed 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).

The infants first saw the near- and far-wall familiarization events appropriate for their condition (inert or self-propelled) on alternate trials for three pairs of trials. Half the infants in each condition saw the near-wall event first, and half saw the far-wall event first. Each familiarization trial ended when the infant either (1) looked away for two consecutive seconds after having looked at it for at least five cumulative seconds, or (2) looked for 60 cumulative seconds without looking away for two consecutive seconds.

Next, the infants saw the near- and far-wall test events appropriate for their condition on alternate trials for two pairs of test trials. The events were presented in the same order as in the familiarization trials. Each test trial ended when the infant (1) looked away for two consecutive seconds after having

[4] There were speed violations in the familiarization and test events shown to the infants in the inert condition, since the box moved at a constant speed (controlled by the motorized system) as it moved back and forth across the apparatus. Nevertheless, as will become clear, the infants in the inert condition of this and the following experiments did categorize the box as inert, suggesting that they were not particularly sensitive to these quantitative speed violations (see Kotovsky and Baillargeon, 1994, 1998, for additional evidence that infants and even adults are often not sensitive to such violations).

looked for at least five cumulative seconds, or (2) looked for 60 cumulative seconds without looking away for two consecutive seconds. The 5-s minimum value corresponded to approximately one event cycle and was chosen to ensure that the infant had sufficient opportunity to notice that the box reversed direction either spontaneously or after hitting the wall partition.[5]

To assess interobserver agreement during the familiarization and test trials, each trial was divided into 100-ms intervals, and the computer determined within each interval whether the two observers agreed on whether the infant was or was not looking at the event. Percent agreement was calculated for each trial by dividing the number of intervals in which the observers agreed by the total number of intervals in the trial. Interobserver agreement was measured for all 32 infants and averaged 94% per trial per infant.

Preliminary analysis of the infants' looking times during the test trials revealed no significant interaction among condition, event, and order, $F(1,24) = 0.54$, or among condition, event, and sex, $F(1,24) = 3.64$, $p > .068$; the data were therefore collapsed across order and sex in subsequent analyses.[6]

2.2. Results

2.2.1. Familiarization trials

The infants' looking times during the three pairs of familiarization trials were averaged and analyzed by means of a 2×2 ANOVA with condition (inert or self-propelled) as a between-subjects factor and event (far- or near-wall) as a within-subject factor. The main effects of condition, $F(1,30) = 0.00$, and event, $F(1,30) = 0.42$, were not significant, nor was the interaction between condition and event, $F(1,30) = 0.70$, indicating that the infants in the two conditions did not differ reliably in their mean looking times at the far- and near-wall familiarization events (inert condition: far-wall event: $M = 44.9$, $SD = 12.7$; near-wall event: $M = 45.2$, $SD = 13.0$; self-propelled condition: far-wall event: $M = 46.2$, $SD = 15.1$; near-wall event: $M = 43.8$, $SD = 17.6$).

2.2.2. Test trials

The infants' looking times during the two pairs of test trials (see Fig. 2) were averaged and analyzed in the same manner as the familiarization data. The main effect of event, $F(1,30) = 9.35$, $p < .005$, and the condition $\times$ event interaction, $F(1,30) = 7.23$, $p < .025$, were significant, but the main effect of condition was not, $F(1,30) = 0.47$. Planned comparisons revealed that the infants in the inert condition looked reliably longer at the far- ($M = 44.5$, $SD = 15.3$) than at the near-wall ($M = 32.0$, $SD = 11.6$) test event, $F(1,30) = 16.53$, $p < .0005$, Cohen's $d = 1.3$, whereas the infants in the self-propelled condition looked about equally at the two events (far-wall event: $M = 35.3$, $SD = 17.9$; near-wall event: $M = 34.5$, $SD = 14.4$), $F(1,30) = 0.07$, $d = 0.1$. In addition, the infants in the inert condition looked reliably longer at the far-wall event than did those in the self-propelled condition, $F(1,30) = 8.85$, $p < .01$, $d = 0.6$, whereas the infants in the inert and self-propelled conditions looked about equally at the near-wall event, $F(1,30) = 0.69$, $d = -0.2$.

Examination of the individual infants' mean looking times during the test trials indicated that, whereas 14 of the 16 infants in the inert condition looked longer at the far- than at the near-wall test

[5] Throughout this article, minimum values for trials corresponded to about one event cycle (or sometimes to a few event cycles when infants seemed to need more opportunity to observe and process the event before the trial ended; this was true especially in experiments where the box remained stationary in test). The minimum value for each type of trial in each experiment was entered in the computer program used to run the experiment. During a session, each trial continued until the infant had satisfied the minimum value set for the trial in the program; after this minimum value was reached, the computer ended the trial according to the criteria set for the experiment in the program. The computer program used to run our infant experiments (the Barrett-Baillargeon Baby program) is available free of charge upon request to the authors.

[6] Although the interaction among condition, event, and sex was marginally significant (this is the only experiment in which this was the case), both the male and the female infants in Experiment 1 responded as predicted. In the inert condition, the male and female infants looked reliably longer at the far- than at the near-wall event (male: far-wall event, $M = 36.3$, $SD = 16.5$; near-wall event, $M = 27.0$, $SD = 11.5$, $F(1,24) = 5.15$, $p < .05$; female: far-wall event, $M = 52.8$, $SD = 8.5$; near-wall event, $M = 37.0$, SD = 10.0, $F(1,24) = 14.90$, $p < .001$). In the self-propelled condition, the male and female infants tended to look equally at the two events (male: far-wall event: $M = 38.0$, $SD = 18.5$; near-wall event: $M = 32.7$, $SD = 14.3$, $F(1,24) = 1.72$, $p > .20$; female: far-wall event: $M = 32.7$, $SD = 18.0$; near-wall event: $M = 36.4$, $SD = 15.2$, $F(1,24) = 0.84$). The marginally significant interaction reflects the fact that the female infants in the inert condition looked longer than the male infants, especially at the far-wall event.

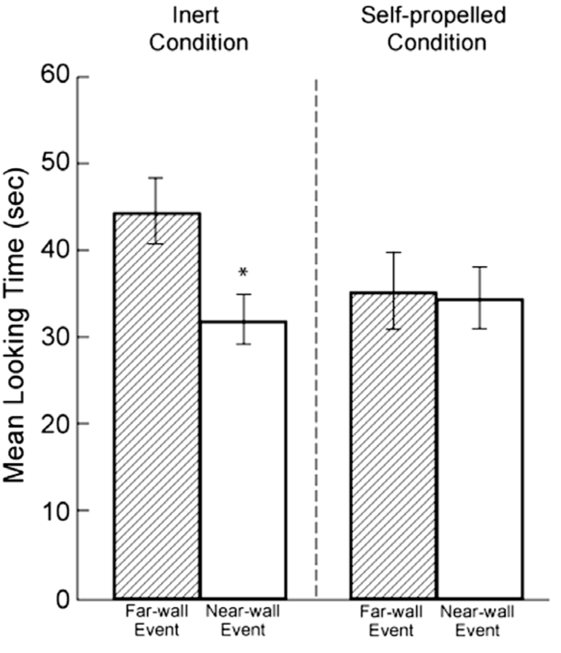

Fig. 2. Mean looking times of the infants in Experiment 1 during the test trials. Error bars represent standard errors. A star (*) indicates $p < .05$.

event, Wilcoxon signed-ranks $T = 8$, $p < .001$, only nine of the 16 infants in the self-propelled condition did so, $T = 59$, $p > .20$.

2.3. Discussion

The infants in the inert condition looked reliably longer at the far- than at the near-wall test event, whereas those in the self-propelled condition looked about equally, and equally short, at the two events. These results suggest that, during the familiarization trials, the infants in the inert condition categorized the box as inert. Since (1) the box began to move only when hit by the hand and (2) it was unclear what caused it to reverse direction behind the screen, the infants had no unambiguous evidence that the box was anything other than inert, and they categorized it as such. During the test trials, the infants expected the box, once in motion, to follow a smooth path, with no abrupt changes in direction, unless acted upon by an external force.[7] As a result, they were surprised in the far-wall event when

[7] Where might such an expectation come from? Research on the development of infants' physical reasoning suggests that infants form categories of events and, for each category, identify the variables relevant for predicting outcomes (for recent reviews, see Baillargeon, Li, Luo, & Wang, 2006; Baillargeon, Li, Ng, & Yuan, 2009). Variables are identified when infants notice unexplained variation in outcome: events with similar representations lead to contrastive outcomes, suggesting that some crucial information is lacking from the representations. In the same manner, infants could identify variables for displacement events. For example, why does an inert object sometimes travel in a straight line and sometimes not? Why does it sometimes travel a greater distance before coming to a stop and sometimes a shorter distance? Why does it sometimes travel at a greater speed and sometimes at a slower speed? In each case, by uncovering the conditions that map onto the different outcomes, infants could identify some of the variables relevant for predicting the outcomes of displacement events. This is not to say that infants would initially have no expectations whatsoever about the displacements of inert objects. We assume that their understanding of forces would lead infants to expect an inert object to move only when acted upon (forces can only be exerted on contact), and indeed infants as young as 2.5 months of age are surprised when an inert object moves without being hit (Kotovsky & Baillargeon, cited in Baillargeon, 1995). Their understanding of forces may also lead infants to expect an inert object at rest to begin to move in the same direction as the force exerted upon it (forces are directional; Leslie, 1994; Leslie, 1995); infants would then learn, as noted above, under what conditions the object is and is not likely to maintain this initial direction.

the box reversed direction spontaneously, but they were not surprised in the near-wall event when it reversed direction after hitting the wall partition.

In contrast, the infants in the self-propelled condition categorized the box as self-propelled during the familiarization trials, since it initiated its own motion in plain view. During the test trials, the infants recognized that the box could alter its trajectory spontaneously—by applying its internal energy—or as a result of external impact. Thus, the infants found neither the far- nor the near-wall test event surprising, and they tended to look equally, and equally short, at the two events.

The results of Experiment 1 thus suggest that, by 5 months of age, infants (1) endow self-propelled but not inert objects with internal energy (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995); (2) expect an object to follow a smooth path unless a force, either internal or external, intervenes to change it; and hence (3) are surprised when an inert but not a self-propelled object abruptly deviates from its initial path without external impact.

2.3.1. Links to prior findings

The results of Experiment 1 also have implications for a number of prior findings. First, the results of the inert condition support the speculation, put forth earlier, that the infants tested by Spelke et al. (1994) failed to detect the path violation they were shown because it was too subtle for them to detect. The infants in the present experiment were presented with a full reversal in plain view, and they had no difficulty detecting this violation.

Second, and relatedly, the results of the inert condition help reconcile previously discrepant findings in the infancy literature. In contrast to the violation-of-expectation findings of Spelke et al. (1994), experiments using action tasks such as predictive reaching (for visible objects) and predictive tracking (for occluded objects) have found that young infants do expect objects to follow a smooth path, with no abrupt change in direction (e.g., Kochukhova & Gredebäck, 2007; Spelke & von Hofsten, 2001; von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998; von Hofsten et al., 2007). These contrastive results have sometimes been taken to point to a possible dissociation between the physical knowledge underlying infants' responses in violation-of-expectation and action tasks (e.g., von Hofsten et al., 1998). However, the positive results of the inert condition in Experiment 1 suggest that young infants can demonstrate an expectation that objects follow a smooth path in violation-of-expectation as well as in action tasks.

To give an example of such an action task, Kochukhova and Gredebäck (2007) showed 6-month-old infants computer-animated events in which a self-propelled object approached and then disappeared behind an occluder; while behind the occluder, the object effected a 90-degree turn (e.g., the object disappeared behind the left edge of the occluder and reappeared at its bottom edge). Analyses of the infants' anticipatory responses using an eye-tracker revealed that, on the initial trials, the infants expected the object to reappear further along its pre-occlusion trajectory, on the opposite side of the occluder (e.g., at the occluder's right edge). After two or three trials, however, the infants began to anticipate the object's reappearance on the correct side of the occluder (e.g., at the occluder's bottom edge). One interpretation of these results is that when watching a self-propelled object move behind an occluder, young infants initially hold the default assumption that the object will follow a smooth path, with no abrupt change in direction, just as they do for an inert object. However, if this expectation is violated, infants conclude that the object is using its internal energy to alter its trajectory when behind the occluder, and they then allow their prior observations (about where the object has reappeared on previous trials) to guide their future anticipations.

Finally, the results of the self-propelled condition in Experiment 1 are consistent with a plethora of experiments over the past 20 years that have presented young infants with a self-propelled object moving back and forth across an apparatus, with or without occluders at the center of the apparatus (e.g., Aguiar & Baillargeon, 1999; Aguiar & Baillargeon, 2002; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Bremner et al., 2005; Johnson, 2004; Johnson, Amso, & Slemmer, 2003; Kellman & Spelke, 1983; Luo & Baillargeon, 2005a; Luo & Baillargeon, 2005b; Slater, Johnson, Brown, & Badenoch, 1996; Spelke, Kestenbaum, et al., 1995; Wilcox, 1999; Wilcox & Baillargeon, 1998; Wilcox & Schweinle, 2003). Though this issue was typically not examined directly, there was no empirical reason to suspect that the infants in these experiments were surprised when the object reversed direction at either end of its trajectory, and the present data support this interpretation.

3. Experiment 2: can an inert or a self-propelled object pass through an obstacle?

The results of Experiment 1 suggested that 5-month-old infants are surprised when an inert but not a self-propelled object spontaneously reverses direction. However, an alternative interpretation of the results was that the infants were confused by the self-propelled box and hence held no specific expectation about its behavior, resulting in equal looking times at the near- and far-wall test events. This interpretation was unlikely: as was mentioned in the last section, numerous experiments over the past 20 years have presented infants with events involving self-propelled objects; had infants found these objects confusing, the results of the experiments would have been consistently negative, and they were not. Nevertheless, Experiment 2 was conducted to directly test this alternative interpretation.

A large body of evidence suggests that young infants interpret physical events in accord with a principle of persistence (e.g., Baillargeon, 2008; Baillargeon, Li, Ng, & Yuan, 2009), which states that objects persist as they are through time and space. An important corollary of this principle is the solidity principle, which states that, for two objects to each persist in time and space, the two cannot occupy the same space at the same time (e.g., Spelke, 1994; Spelke, Phillips, et al., 1995). Numerous investigations have shown that infants aged 2.5 months and older recognize that an object, whether self-propelled or not, cannot pass through space occupied by another object (e.g., Aguiar & Baillargeon, 1998; Aguiar & Baillargeon, 2003; Baillargeon, 1986; Baillargeon, 1987; Baillargeon, 1991; Baillargeon & DeVos, 1991; Baillargeon, Graber, DeVos, & Black, 1990; Baillargeon et al., 1985; Hespos & Baillargeon, 2001b; Luo et al., 2003; Saxe, Tzelnic, & Carey, 2006; Sitskoorn & Smitsman, 1995; Spelke et al., 1992; Wang et al., 2004; Wang et al., 2005). Experiment 2 therefore examined whether 5-month-old infants would recognize that an object, whether self-propelled or not, cannot pass through another object.

The infants were assigned to an inert or a self-propelled condition (see Fig. 3). The infants in the self-propelled condition first received familiarization trials identical to those in Experiment 1 except that—in these trials as in all other trials in Experiment 2—the wall partition was always in the far position. Next, the infants received two orientation trials in which they were introduced to a large table and a large block. Finally, the infants were shown a table and a block test event. At the start of the table event, the table rested across the box's path on the apparatus floor, directly in front of the infants; the box began to move to the right, passed under the table, reversed direction, passed under the table once more, and finally returned to its starting position. The block event was similar except that the table was replaced with the block; the box appeared to pass through the block once as it travelled to the right and once more after it reversed direction to return to its starting position. The infants in the inert condition saw the same familiarization, orientation, and test events, except that the box did not initiate its own motion: as in the inert condition of Experiment 1, the box began to move only after it was hit by the experimenter's gloved hand.

We reasoned that if the infants in the self-propelled condition of Experiment 1 looked about equally at the test events because they were confused by our self-propelled box, then the infants in the self-propelled condition of Experiment 2 should also be confused and hence should also look about equally at the test events. However, if the infants in the self-propelled condition of Experiment 1 looked about equally at the test events because they realized that the box could reverse its motion either spontaneously or following its impact with the wall partition, then the infants in Experiment 2 should respond differentially to the block and table test events. Because by 5 months infants realize that an object, whether self-propelled or not, cannot pass through another object (e.g., Baillargeon, 1987; Baillargeon, 1991; Baillargeon & DeVos, 1991; Baillargeon et al., 1985; Baillargeon et al., 1990; Hespos & Baillargeon, 2001b; Luo et al., 2003; Saxe et al., 2006; Spelke et al., 1992; Wang et al., 2004; Wang et al., 2005), the infants should be surprised when the box appeared to pass through the block but not under the table. The infants should thus look reliably longer at the block than at the table event.

In contrast to the infants in the self-propelled condition, those in the inert condition should find both test events surprising: the table event, because the box appeared to reverse direction spontaneously (as in the far-wall test event of Experiment 1); and the block event, because the box appeared to

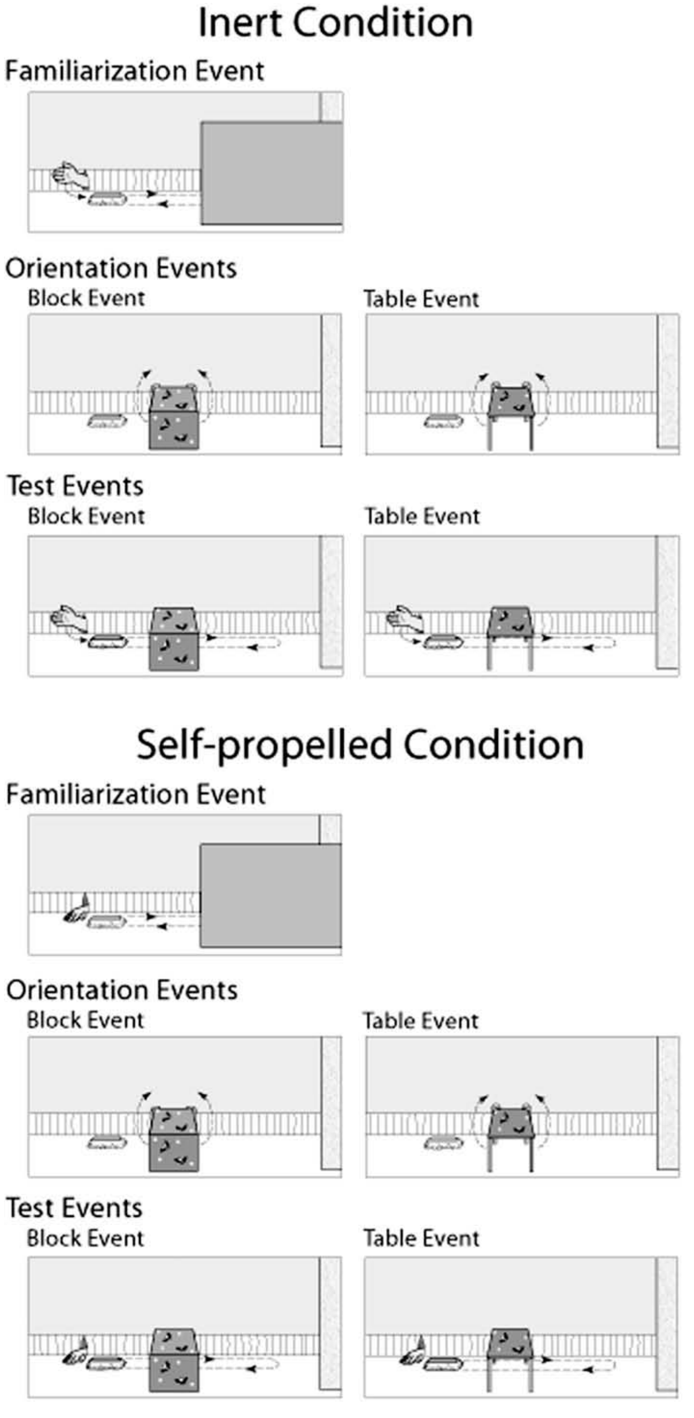

Fig. 3. Schematic drawing of the familiarization, orientation, and test events in Experiment 2.

reverse direction spontaneously and to pass through the block. The infants should tend to look equally, and equally long, at the block and table events.[8]

3.1. Method

3.1.1. Participants

Participants were 32 healthy term infants, 16 male and 16 female, ranging in age from 4 months, 16 days to 5 months, 9 days (*M* = 5 months, 1 day, *SD* = 6.4 days). Another eight infants were tested but eliminated, six because they looked for the maximum amount of time allowed (60 s) on all four test trials, one because of drowsiness, and one because of observer difficulties. Half the infants were randomly assigned to the inert condition (eight male and eight female; *M* = 5 months, 1 day, *SD* = 6.5 days), and half to the self-propelled condition (*M* = 5 months, 0 day, *SD* = 6.5 days).

3.1.2. Apparatus

The apparatus and stimuli used in Experiment 2 were identical to those in Experiment 1 except as noted here. The wall partition remained in the far position throughout Experiment 2. The table used in the table orientation and test events was 17 cm high, 22 cm wide and 69 cm deep. The top of the table was made of cardboard, was 0.3 cm thick, was covered on both sides with a blue contact paper decorated with red and white sailboat stickers and small yellow dots, and rested on four thin legs, one in each corner. Each table leg consisted of a wooden rod, 16.7 cm high, 0.7 cm in diameter, and painted blue. A different block was used in the block orientation and test events. The orientation block was made of cardboard, was 17 cm high, 22 cm wide and 69 cm deep, and was covered with the same contact paper as the table. The test block was identical except that a tunnel was cut through it, to allow the box to pass through. The opening of the tunnel on either side of the box was 6.5 cm high and 21 cm wide; the opening was located 22.5 cm from the front of the block. Because the infants sat centered in front of the block, they could not see the opening of the tunnel on either side of the block. During the table and block orientation events, the experimenter wore yellow rubber gloves and introduced both hands into the apparatus through the gray fringe at the bottom of the back wall.

3.1.3. Events

3.1.3.1. Inert condition. Familiarization event. The familiarization event shown in the inert condition of Experiment 2 was identical to the far-wall familiarization event shown in the inert condition of Experiment 1.

Table orientation event. Prior to the orientation events, the screen used in the familiarization trials was removed. At the beginning of the table orientation event, the box rested in its starting position at the left end of the slit; the table stood on the apparatus floor against the back wall, 12.5 cm to the right of the box, directly in front of the infants; and the experimenter's gloved hands grasped the left and right sides of the table. To start, the hands rotated the table 90° upward (3 s) until it stood against the back of the apparatus, with its inside top surface facing the infant. After a 2-s pause, the hands returned the table to its original position on the apparatus floor (3 s) and then paused for another 2 s. Each event cycle thus lasted approximately 10 s. Cycles were repeated until the computer signaled that the trial had ended.

Block orientation event. The block orientation event was identical to the table orientation event except that the table was replaced with the (closed) orientation block.

Table test event. The table test event was identical to the familiarization event except that the screen was absent and the table was in place. After the box was hit by the experimenter's gloved hand, it moved to the right, passed under the table, reversed direction, passed under the table once more,

[8] Readers might wonder why we did not predict that the infants in the inert condition would look reliably longer at the block than at the table test event, since the block event was, in a sense, doubly surprising: the box not only reversed on its own but also passed through the block. The reason we did not is that in our experience the violation-of-expectation method typically functions as a categorical rather than as a proportional measure: it tells us whether infants view an event as unexpected, not how unexpected it appears to them.

and finally returned to its starting position. Because the table was 69 cm deep and stood on four thin legs, there was visibly ample room for the box to pass through.

Block test event. The block test event was identical to the table test event except that the table was replaced with the test block; the tunnel in the block lay centered over the box's path, allowing the box to move back and forth across the apparatus. After the box was hit by the experimenter's gloved hand, it moved to the right, passed through the block, reversed direction, and finally passed through the block once more as it returned to its starting position.

3.1.3.2. Self-propelled condition. The events shown in the self-propelled condition were similar to those in the inert condition except that during the familiarization and test trials the experimenter's gloved right hand remained stationary on the apparatus floor, 9 cm to the left of the box in its starting position. As in the self-propelled condition of Experiment 1, the experimenter depressed a button on the control panel under the apparatus to set the box into motion.

3.1.4. Procedure

The procedure used in Experiment 2 was similar to that in Experiment 1 except that the infants received two orientation trials between the familiarization and test trials. Half the infants in each condition saw the table orientation and test events first, and half saw the block orientation and test events first. Each orientation trial ended when the infant (1) looked away for two consecutive seconds after having looked for at least 10 cumulative seconds, or (2) looked for 60 cumulative seconds without looking away for two consecutive seconds. The 10-s minimum value corresponded to one event cycle and was chosen to give the infant ample exposure to the table or block. During the orientation trials, the primary observer was absent so that he or she could not guess from available noise cues whether the table or block was introduced first (because the table was lighter than the block, it made less noise when lowered onto the apparatus floor). Therefore, the infant's looking behavior during the orientation trials was monitored only by the secondary observer. Interobserver agreement during the familiarization and test trials was measured for 31 of the 32 infants and averaged 95% per trial per infant.

Preliminary analysis of the infants' looking times during the test trials revealed no significant interaction among condition, event, and order, $F(1,24) = 1.20$, $p > .28$, or among condition, event, and sex, $F(1,24) = 0.38$; the data were therefore collapsed across order and sex in subsequent analyses.

3.2. Results

3.2.1. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and analyzed as in Experiment 1. The analysis yielded a significant effect of condition, $F(1,30) = 9.13$, $p < .01$, indicating that the infants in the inert condition ($M = 47.6$, $SD = 7.0$) looked reliably longer during the familiarization trials than did those in the self-propelled condition ($M = 35.5$, $SD = 14.5$).

Examination of the familiarization data in Experiments 1 and 2 makes clear that, whereas the infants in the inert condition looked about as long in the two experiments, those in the self-propelled condition looked less in Experiment 2 than in Experiment 1. Why this was the case is unclear, as the infants in the self-propelled condition of the two experiments saw essentially the same familiarization event (the only difference was that in Experiment 1 the wall partition was placed in the near and far positions on alternate trials). Since the infants in the self-propelled condition of Experiment 2 responded as expected in subsequent trials, and since this is the only experiment where a difference was found in the responses of the infants in the inert and self-propelled conditions during the familiarization trials, we attribute this difference to sampling variation.

3.2.2. Orientation trials

The infants' looking times during the two orientation trials were analyzed by means of a 2×2 ANOVA with condition (inert or self-propelled) as a between-subjects factor and with event (block or table) as a within-subject factor. The main effects of condition, $F(1,30) = 0.76$, and event, $F(1,30) = 0.82$, were not significant, nor was the condition $\times$ event interaction, $F(1,30) = 0.21$, indicating that the infants in the two conditions did not differ reliably in their looking times at the block and table orien-

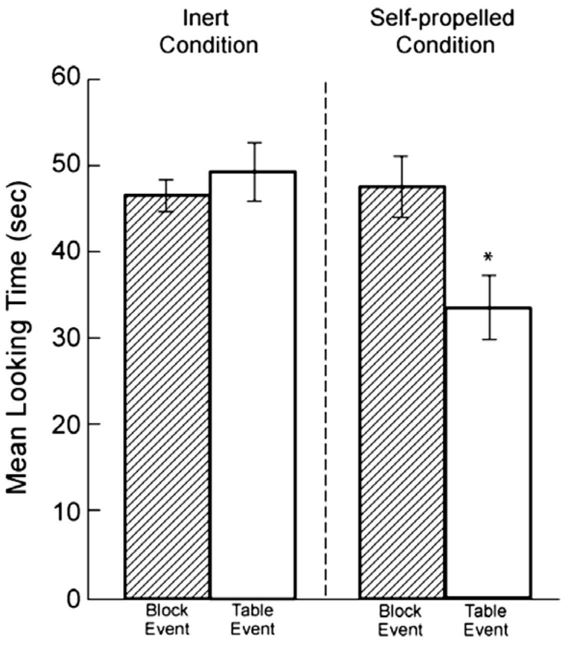

Fig. 4. Mean looking times of the infants in Experiment 2 during the test trials. Error bars represent standard errors. A star (∗) indicates $p < .05$.

tation events (inert condition: block event: $M = 54.2$, $SD = 12.9$; table event: $M = 52.5$, $SD = 15.5$; self-propelled condition: block event: $M = 52.3$, $SD = 16.0$; table event: $M = 47.2$, $SD = 18.2$).

3.2.3. Test trials

The infants' looking times during the two pairs of test trials (see Fig. 4) were averaged and analyzed in the same manner as the orientation trials. The analysis yielded a marginally significant main effect of condition, $F(1,30) = 3.63$, $p < .07$, a significant main effect of event, $F(1,30) = 5.58$, $p < .025$, and a significant condition × event interaction, $F(1,30) = 12.21$, $p < .0025$. Planned comparisons indicated that the infants in the inert condition looked about equally at the block ($M = 46.8$, $SD = 7.4$) and table ($M = 49.6$, $SD = 13.5$) events, $F(1,30) = 0.64$, $d = -0.2$, whereas those in the self-propelled condition looked reliably longer at the block ($M = 47.8$, $SD = 14.5$) than at the table ($M = 33.7$, $SD = 15.2$) event, $F(1,30) = 17.15$, $p < .0005$, $d = 1.4$. In addition, although the infants in the inert and self-propelled conditions looked about equally at the block event, $F(1,30) = 0.07$, $d = -0.1$, the infants in the inert condition looked reliably longer at the table event than did those in the self-propelled condition, $F(1,30) = 21.78$, $p < .0001$, $d = 1.1$.

Examination of the individual infants' mean looking times indicated that, whereas 14 of the 16 infants in the self-propelled condition looked longer at the block than at the table event, $T = 6$, $p < .0005$, only five of the 16 infants in the inert condition did so, $T = 53$, $p > .20$.[9]

[9] Because the analysis of the familiarization data yielded a significant main effect of condition, the infants' test looking times were also subjected to an analysis of covariance (ANCOVA), using as covariates the infants' mean looking times during the six familiarization trials and their looking times during the block and table orientation trials. As in the ANOVA, the condition x event interaction was significant, $F(1,27) = 5.68$, $p < .025$. Planned comparisons confirmed that: the infants in the inert condition looked about equally at the block and table events, $F(1,27) = 0.09$; the infants in the self-propelled condition looked reliably longer at the block than at the table event, $F(1,27) = 12.79$, $p < .0025$; the infants in the inert and self-propelled conditions looked about equally at the block event, $F(1,27) = 2.78$, $p > .10$; and the infants in the inert condition looked reliably longer at the table event than did those in the self-propelled condition, $F(1,27) = 4.90$, $p < .05$.

3.3. Discussion

During the test trials, the infants in the self-propelled condition looked reliably longer at the block than at the table event, whereas the infants in the inert condition looked about equally, and equally long, at the two events. These results suggest that the infants in the self-propelled condition (1) categorized the box as self-propelled during the familiarization trials, since it initiated its own motion in plain sight; (2) realized that the box could not only initiate but also alter its motion; (3) understood that the box could pass under the table but not through the block; and hence (4) were surprised in the block event when the box appeared to pass through the block. These results cast doubt on the suggestion that the infants in the self-propelled condition of Experiment 1 looked about equally at the test events because they were confused by the self-propelled box and hence held no expectation about its behavior. The infants in the self-propelled condition of Experiment 2 saw the same self-propelled box and clearly had an expectation that it could not pass through the block.

The results of Experiment 2 also suggest that the infants in the inert condition (1) categorized the box as inert, since they were given no evidence to the contrary; (2) expected the box, once set into motion by the hand, to follow a smooth path; (3) realized that the box could pass under the table but not through the block; and hence (4) found both test events surprising: the table event, because the box spontaneously reversed its trajectory, and the block event, because the box not only reversed its trajectory but also appeared to pass through the block.

Together, the results of the inert and self-propelled conditions in Experiment 2 confirm those of Experiment 1: they provide additional evidence that 5-month-old infants are surprised when an inert but not a self-propelled object spontaneously reverses direction. In addition, the results confirm prior evidence that young infants interpret physical events in accord with a solidity principle and realize that two objects, whether inert or self-propelled, cannot occupy the same space at the same time (e.g., Baillargeon, 1987; Hespos & Baillargeon, 2001b; Luo et al., 2003; Saxe et al., 2006; Spelke et al., 1992; Wang et al., 2004).

More generally, the results of Experiments 1 and 2 support the hypothesis that infants endow self-propelled objects with an internal source of energy (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995). By 5 months of age, infants are not surprised when a self-propelled object spontaneously reverses its motion, because they realize that the object can use its internal energy to do so. However, they are surprised when a self-propelled object appears to pass though an obstacle, because they understand that no application of internal energy could enable the object to occupy the same space as the obstacle.

4. Experiment 3: can an inert or a self-propelled object remain stationary when hit or pulled?

We have seen that young infants appreciate that a self-propelled object can use its internal energy to reverse its motion. In Experiment 3, we asked whether young infants also believe that a self-propelled object can use its internal energy to resist efforts to move it and hence to remain stationary when hit or pulled.

The point of departure for this experiment came from investigations of infants' responses to collision events. Prior research with inert objects (e.g., Baillargeon, 1995; Kotovsky & Baillargeon, 1998; Kotovsky & Baillargeon, 2000; Wang, Kaufman, & Baillargeon, 2003) suggests that, when a first object hits a second object, infants as young as 2.5 months of age expect the second object to be displaced and are surprised if it is not. By 5.5 to 6.5 months of age, infants begin to take into account the size (or weight) of the first object, and they now expect the second object to be displaced farther when hit by a larger as opposed to a smaller object. Finally, by about 9 months of age, infants begin to take into account the size (or weight) of the second object, and they now expect a very large object to remain stationary when hit by a small object. Prior research with self-propelled objects (e.g., Leslie, 1982; Leslie, 1984b; Leslie & Keeble, 1987; Oakes, 1994), however, paints a different picture: in particular, it suggests that young infants may not expect a self-propelled object to be displaced when hit.

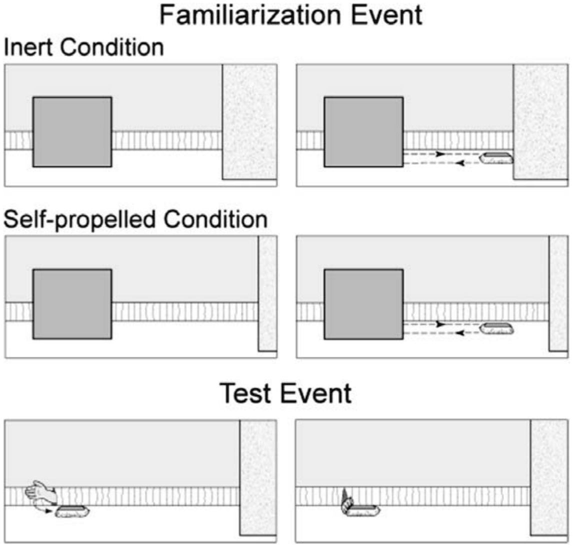

Fig. 5. Schematic drawing of the familiarization and test events in Experiment 3.

In a seminal experiment, Leslie and Keeble (1987) habituated 6-month-old infants to one of two filmed events; both events involved two self-propelled objects, a red and a green brick.[10] In one event (launching event), one brick began to move toward the other brick and collided with it; the second brick then immediately moved off. In the other event (delayed-reaction event), the second brick moved off only after a 0.5-s delay. During test, the infants watched the same event they had seen during habituation, now shown in reverse. The results of the test trials indicated that the infants habituated to the launching event showed greater recovery of attention than those habituated to the delayed-reaction event. This finding suggested that the infants attributed a causal role to the first brick only in the launching event: they assumed that the first brick caused the second one to move in the habituation trials, and they looked reliably longer when the bricks' causal roles were reversed in the test trials.

From the present perspective, the results of the habituation trials were just as interesting: the infants tended to look equally whether they were shown the launching or the delayed-reaction event (see also Leslie, 1982; Leslie, 1984b; Oakes, 1994). This finding suggested that the infants were not surprised that the second brick did not move off immediately when hit, because they understood that the second brick could use its internal energy to counteract the impact from the first brick. As such, this finding gave rise to the possibility that infants might not be surprised if a self-propelled object did not move off at all when hit. Experiment 3 was designed to test this possibility: it asked whether 6-month-old infants would be surprised if an inert but not a self-propelled object remained stationary when hit.

The infants were assigned to an inert or a self-propelled condition and saw familiarization and test events involving the same box as in the previous experiments (see Fig. 5). All of the infants saw the same test event, on two successive trials: the experimenter's gloved hand hit the box, which remained

[10] Because the first brick always initiated its motion in plain view, and the two bricks differed only in color, we assume that the infants viewed not only the first brick, but both bricks, as self-propelled. In the same vein, we suggested in Footnote 1 that the infants tested by Kosugi and Fujita (2002) viewed both blocks (which differed mainly in width and color) as self-propelled, after seeing the first block initiate its motion. However, it is possible that our analysis overestimates the role of perceptual similarity in infants' reasoning about self-propelled objects, and that in the experiment of Leslie and Keeble (1987) only the infants who saw the delayed-reaction event actually viewed the second brick as self-propelled. This alternative interpretation is still consistent with the conclusion (suggested by the habituation data) that infants are not surprised when a self-propelled object does not move immediately after being hit by another object, and it is this conclusion that served as the point of departure for Experiment 3.

stationary. As before, the infants received familiarization trials prior to the test trials that made clear whether the box was inert or self-propelled. Given the nature of the test event, however, we could no longer use the same familiarization events as in the preceding experiments. Accordingly, we designed new familiarization events that built on the results of Experiments 1 and 2.

At the start of the familiarization event shown in the self-propelled condition, the wall partition was in its far position, and the box rested in its usual starting position at the left end of the slit; however, the box was now hidden by a large screen. During the event, the box emerged to the right of the screen, travelled to the right a short distance, reversed direction on its own (at its usual reversal point), and returned behind the screen. The familiarization event shown in the inert condition was similar except that the wall partition was in its near position: the box thus hit the wall partition before reversing direction and returning behind the screen. The familiarization event in the self-propelled condition thus presented the infants with unambiguous evidence that the box was self-propelled, since it reversed direction spontaneously. In contrast, the familiarization event shown in the inert condition presented the infants with no such evidence, since (1) it was unclear what caused the box to emerge from behind the screen, and (2) the box reversed direction as a result of external impact, after hitting the wall partition; on the default assumption that an object is inert until proven otherwise, the infants should categorize the box as inert.

In line with previous research (e.g., Baillargeon, 1995; Kotovsky & Baillargeon, 2000; Wang et al., 2003), we predicted that, when shown the test event, the infants in the inert condition would expect the box to move when hit and would be surprised that it did not. But how would the infants in the self-propelled condition respond? We reasoned that if the infants endowed the self-propelled box with an internal source of energy (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995), they might consider it possible for the box to use its internal energy to counteract the hand's impact. The infants might thus show little or no surprise that the box failed to move when hit, because they could readily generate an explanation for this outcome. We thus predicted that the infants in the inert condition would look reliably longer during the test trials than those in the self-propelled condition.

4.1. Method

4.1.1. Participants

Participants were 16 healthy term infants, eight male and eight female, ranging in age from 5 months, 20 days to 6 months, 21 days (M = 6 months, 0 day, SD = 10.7 days). Another two infants were tested but eliminated, one because of fussiness and one because he looked for the maximum amount of time allowed (60 s) on both test trials. Half the infants were randomly assigned to the inert condition (four male and four female; M = 6 months, 1 day, SD = 12.0 days), and half to the self-propelled condition (M = 6 months, 0 day, SD = 10.2 days).

4.1.2. Apparatus

The apparatus and stimuli used in Experiment 3 were identical to those in Experiment 1 except that a different screen was used during the familiarization trials. This screen was 39.5 cm high, 44.5 cm wide, and 0.5 cm thick, was covered with green contact paper, and was supported at the back by a metal base. During the familiarization trials, the screen stood centered in front of the box in its starting position, 16 cm from the left wall and 18 cm from the front edge of the apparatus. During the familiarization trials, the wall partition was in the near position in the inert condition and in the far position in the self-propelled condition. During the test trials, the wall partition was in a new position, midway between the near and far positions, 133 cm from the left wall (we will refer to this position of the wall partition as the midway position); the front surface of the wall partition was then 31 cm wide.

4.1.3. Events

4.1.3.1. Inert condition. Familiarization event. At the start of the familiarization event, the wall partition was in its near position, and the box rested in its starting position at the left end of the slit, hidden behind the screen. After a 1-s pause, the experimenter pressed the button on the control panel beneath the apparatus to initiate the box's motion (1 s). The box then emerged to the right of the familiarization screen, travelled to the right a short distance, hit the wall partition, reversed direction (as though bouncing back), and returned to its starting position behind the screen (3 s). After a 1-s pause, the event was repeated. Each event cycle thus lasted about 6 s; cycles were repeated until the computer signaled the end of the trial (see below).

Test event. During the test event, the wall partition was in the midway position. The box rested at the left end of the slit, in its starting position, and the screen was removed from the apparatus. The motorized system was disabled and the box was anchored under the apparatus so that it could not move. At the start of the event, the experimenter's right hand (in the same golden spandex glove as in Experiment 1) rested palm down on the apparatus floor, 9 cm to the left of the box. The hand rotated 90° (so the palm now faced the box) while swinging back (1 s), and hit the box (1 s), which remained stationary. After hitting the box, the hand rested on the apparatus floor with its palm facing the box, 4.5 cm from the left edge of the box (2 s). The hand then returned to its starting position (1 s). After a 1-s pause, the event was repeated. Each event cycle thus lasted about 6 s; cycles were repeated until the computer signaled the end of the trial.

4.1.3.2. Self-propelled condition. The familiarization and test events shown in the self-propelled condition were identical to those in the inert condition except that in the familiarization event the wall partition was placed in the far position. The box thus appeared to reverse direction spontaneously, without hitting the wall partition.

4.1.4. Procedure

The infants first saw the familiarization event appropriate for their condition (inert or self-propelled) on six successive trials. Each trial ended when the infant (1) looked away for two consecutive seconds after having looked at it for at least six cumulative seconds, or (2) looked for 60 cumulative seconds without looking away for two consecutive seconds. The 6-s minimum value corresponded to one event cycle and was chosen to ensure that the infant had the opportunity to see the box's reversal. Next, all of the infants saw the test event for two successive trials. Each trial ended when the infant (1) looked away for one consecutive second after having looked for at least 18 cumulative seconds, or (2) looked for 60 cumulative seconds without looking away for one consecutive second. The 18-s minimum value corresponded to three event cycles and was chosen to give the infants ample opportunity to observe that the box remained stationary after being hit (i.e., the infants could see that the hand had not accidentally missed the box—it hit the box squarely and yet the box did not move). Interobserver agreement during the familiarization and test trials was calculated for all 16 infants and averaged 92% per trial per infant.

Preliminary analysis of the infants' looking times during the test trials revealed no significant interaction between condition and sex, $F(1,12) = 0.55$; the data were therefore collapsed across sex in subsequent analyses.

4.2. Results

4.2.1. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and analyzed by means of a single-factor ANOVA with condition (inert or self-propelled) as a between-subjects factor. The main effect of condition was not significant, $F(1,14) = 0.01$, indicating that the infants in the two conditions did not differ reliably in their mean looking times during the familiarization trials (inert condition: $M = 35.6$, $SD = 9.7$; self-propelled condition: $M = 35.1$, $SD = 9.3$).

4.2.2. Test trials

The infants' looking times during the two test trials (see Fig. 6) were averaged and analyzed in the same manner as the familiarization data. The main effect of condition was significant, $F(1,14) = 5.53$, $p < .05$, $d = 1.2$, indicating that the infants in the inert condition ($M = 43.5$, $SD = 10.7$) looked reliably longer than did those in the self-propelled condition ($M = 32.4$, $SD = 8.0$) during the test trials. A Wilcoxon rank-sum test confirmed this result, $W = 48$, $p < .05$.

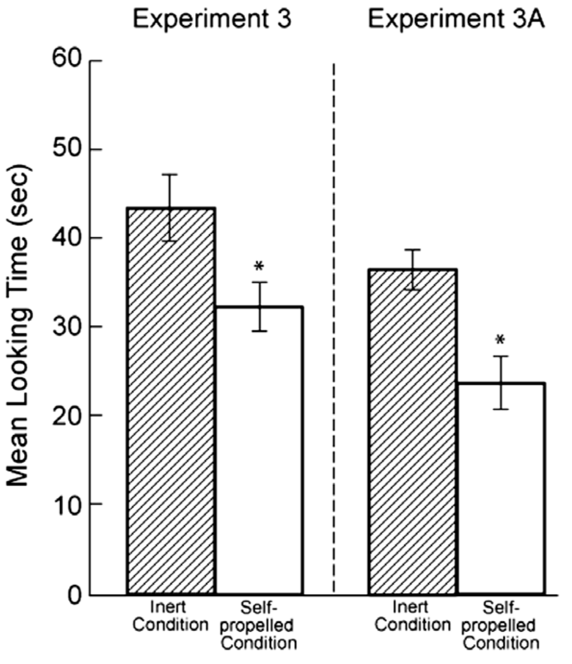

Fig. 6. Mean looking times of the infants in Experiments 3 and 3A during the test trials. Error bars represent standard errors. A star (∗) indicates $p < .05$.

4.2.3. *Further results: Experiment 3A*

The results of Experiment 3 suggested that (1) during the familiarization trials, the infants categorized the box as self-propelled when it reversed direction spontaneously and as inert when it did not, and (2) during the test trials, the infants were surprised when the inert but not the self-propelled box remained stationary when hit. These results suggested that the infants in the self-propelled condition endowed the box with a source of internal energy, and inferred that the box used its internal energy to counteract the hand's impact.

To provide converging evidence for these results, additional 6-month-old infants were tested using a similar procedure except that, instead of hitting the box in the test event, the hand pulled on a strap attached to the left side of the box. As in Experiment 3, the box remained stationary when acted upon.

Participants were 16 healthy term infants, seven male and nine female, ranging in age from 5 months, 20 days to 6 months, 15 days (M = 6 months, 4 days, SD = 6.5 days). Another five infants were tested but eliminated, four because the infants looked for the maximum amount of time allowed (60 s) on both test trials, and one because of fussiness. Half the infants were randomly assigned to the inert condition (three male and five female; M = 6 months, 3 days, SD = 5.1 days), and half to the self-propelled condition (M = 6 months, 5 days, SD = 7.9 days).

The apparatus, stimuli, events, and procedure used in Experiment 3A were similar to those in Experiment 3, with the following exceptions. The strap attached to the left side of the box consisted of two white cotton braids joined at the end with red tape; each braid was 13 cm long and 1 cm in diameter. During the familiarization trials, the strap brushed noiselessly against the apparatus floor as the box moved back and forth across the apparatus. At the start of the event shown in the test trials, the experimenter's gloved hand held the strap folded against the box's left side. After a 1-s pause, the hand stretched the strap to its full length at an upward angle (1 s), in an apparent effort to pull the box to the left, and maintained this position for 1 s. Next, the hand again folded the strap against the left side of the box (1 s). Each event cycle thus lasted about 4 s. Because each cycle was shorter than in Experiment 3 (four instead of 6 s), each test trial ended when the infant (1) looked away for one consecutive second after having looked for at least 12 cumulative seconds, or (2) looked for 60 cumulative seconds without looking away for one consecutive second. The 12-s minimum value corresponded to three event cycles and was chosen to give the infants ample opportunity to observe that the box remained stationary when pulled. Interobserver agreement during the familiarization and test trials was measured for all 16 infants and averaged 91% per trial per infant. Preliminary analysis of infants' looking times during the test trials revealed no significant interaction between condition and sex, $F(1,12) = 0.00$; the data were therefore collapsed across sex in subsequent analyses.

The infants' looking times during the six familiarization trials were averaged and analyzed as in Experiment 3. The main effect of condition was not significant, $F(1,14) = 1.80$, $p > .20$, indicating that the infants in the two conditions did not differ reliably in their mean looking times during the familiarization trials (inert condition: $M = 32.7$, $SD = 5.6$; self-propelled condition: $M = 39.9$, $SD = 14.1$). The infants' looking times during the two test trials (see Fig. 6) were averaged and analyzed as in Experiment 3. The main effect of condition was significant, $F(1,14) = 11.56$, $p < .005$, $d = 1.7$, indicating that the infants in the inert condition ($M = 36.7$, $SD = 6.5$) looked reliably longer than those in the self-propelled condition ($M = 23.8$, $SD = 8.5$). A non-parametric Wilcoxon rank-sum test confirmed this result ($W = 44$, $p < .025$).

4.3. Discussion

In both Experiments 3 and 3A, the infants in the inert condition looked reliably longer at the test event than did those in the self-propelled condition. These data support three conclusions. First, in each experiment, the infants categorized the box as self-propelled when it reversed direction on its own and as inert when it reversed direction only after hitting the wall partition. These results confirm those of Experiments 1 and 2—a self-propelled object can reverse direction spontaneously—and also suggest that infants can use multiple cues to categorize objects as self-propelled: an object is viewed as self-propelled if it begins to move or reverses direction on its own.

Second, the results of Experiments 3 and 3A suggest that 6-month-old infants expect an inert object to move when hit or pulled, and they are surprised when it does not. This result is consistent with prior research on infants' responses to collision events involving inert objects (e.g., Kotovsky & Baillargeon, 2000; Wang et al., 2003).

Third, and most importantly for present purposes, the results of Experiments 3 and 3A make clear that 6-month-old infants are not surprised when a self-propelled object remains stationary when hit or pulled. These results suggest that infants endow a self-propelled object with an internal source of energy (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995) and assume that the object can use this energy to resist or counteract efforts to move it. As such, the present results are consistent with prior evidence that infants are not surprised when a self-propelled object does not move immediately when hit (e.g., Leslie, 1982; Leslie, 1984b; Leslie & Keeble, 1987; Oakes, 1994). Infants apparently assume that a self-propelled object can elect to go along with efforts to move it, or it can elect to resist these efforts—in which case it may choose to move after a delay, or not at all.

4.3.1. Links to prior findings: expecting self-propelled objects to move again

Markson and Spelke (2006) adapted a paradigm developed by Pauen (2000; Träuble, Pauen, Schott, & Charalampidu, 2006) to examine infants' ability to learn which object was inert and which was self-propelled in a pair of objects. In a series of experiments, 7-month-old infants watched two familiarization events involving two different wind-up toys from the same category (e.g., two animals, two vehicles, or two amorphous shapes consisting of the toy animals covered with various materials). In one event, an experimenter's hand held one object (e.g., a bear) and moved it across the apparatus (inert event). In the other event, the hand held a different object (e.g., a rabbit) and released it; the object then moved across the apparatus until it was stopped by the hand (self-propelled event). During the test trials, the two objects stood apart and motionless on the apparatus floor, and the infants' looking time at each object was measured. Analysis of the test data revealed that (1) the infants looked reliably longer at the self-propelled object, as though anticipating that it would move again, and (2) this result was obtained when the two objects were animals but not when they were vehicles or shapes. Markson and Spelke concluded that the infants could "reliably learn the property of self-propelled motion only for animate objects" (p. 67).

This conclusion is surprising in light of the results of the present experiments, where infants readily learned whether the box shown in the familiarization trials was inert or self-propelled. However, Shutts, Markson, and Spelke (in press) recently suggested that extraneous factors might have contributed to the differential results Markson and Spelke (2006) obtained with their animals, vehicles, and shapes. Specifically, when released by the hand, the animals moved in a way that clearly suggested they were self-propelled because they had various parts that moved independently (e.g., a mouth that opened or a head that bobbed up and down); in contrast, the vehicles and shapes moved rigidly across the apparatus, leaving open the possibility that the hand had set them in motion when releasing them. According to this interpretation, the infants failed to learn which object in each pair of vehicles or shapes was self-propelled simply because they received no clear evidence that either object was in fact self-propelled. To test their interpretation, Shutts et al. conducted experiments with vehicles and other objects that gave unambiguous evidence of self-propulsion (e.g., a truck that had independently moving parts and periodically changed direction or a shape that flipped over backwards several times). As predicted, and consistent with the findings of the present experiments, infants now learned which object was inert and which was self-propelled in all pairs of objects.

A separate issue raised by the results of Markson and Spelke (2006), Shutts et al. (in press), and Pauen (2000; Träuble et al., 2006) is the following: one might ask why in Experiments 3 and 3A the infants in the self-propelled condition did not look reliably longer than those in the inert condition, as though expecting the self-propelled box to move again. A simple explanation might be that, because the gloved hand repeatedly hit or pulled the box during the test trials, the infants in Experiments 3 and 3A tended to focus on these events and their outcomes. Had the box stood motionless on the apparatus floor, without being acted on by the hand, the results reviewed above suggest that the infants in the self-propelled condition would have looked longer than those in the inert condition, as though waiting for the self-propelled box to move again.

4.3.2. Links to prior findings: inferring the hidden cause of an inert object's motion

In the familiarization event shown in the inert conditions of Experiments 3 and 3A, the box emerged to the right of the screen, hit the wall partition, and returned behind the screen. To ascertain whether the box was inert or self-propelled, the infants had to determine whether it emerged on its own or not; because the screen was very large, it left open the possibility that some entity behind the screen set the box into motion (in related pilot work, we found suggestive evidence that the smaller the screen, the less likely the infants were to see the box as inert). But what entity did the infants assume was present behind the screen? In such situations, do infants hold the default assumption that the hidden entity is likely to be self-propelled (and human)? Or do infants hold no specific assumption, as though they recognize that the hidden entity could be a self-propelled object <u>or</u> an inert object already in motion? As we saw earlier, prior research on collision events indicates that infants have no difficulty reasoning about events in which a moving inert object hits a stationary inert object and sets it in motion (e.g., Kotovsky & Baillargeon, 1998; Kotovsky & Baillargeon, 2000; Spelke, Phillips, et al., 1995; Wang et al., 2003; Woodward et al., 1993). Infants thus seem to recognize that an inert object resting on a horizontal surface may be set in motion by any object that can exert a force upon it—be it a self-propelled object or an inert object already in motion.

Future research will need to specify what inferences infants draw about the hidden causes of inert objects' motion. In recent experiments, a number of investigators have begun to examine a complementary question: when an inert object moves into view, can infants judge whether a given object could have set it into motion (e.g., Kosugi et al., 2003; Saxe et al., 2005; Saxe et al., 2007)? For example, in an experiment by Saxe et al. (2007), 7-month-old infants saw two boxes standing left and right of midline on an apparatus floor; each box had no top and no back. During the habituation event, a beanbag was thrown out of one of the boxes (right box for half the infants, left box for the others) and landed on the apparatus floor between the boxes. Next, the infants saw two test events similar to the habituation event except that, after the beanbag came to rest on the apparatus floor, the fronts of the boxes were lowered. In the same-side event, the infants saw a stationary human hand in the box from which the beanbag had been thrown (the hand emerged from a curtain at the back of the apparatus), and a block in the other box. In the different-side event, the positions of the hand and block were reversed. The infants looked reliably longer at the different- than at the same-side event, suggesting that they categorized the hand as self-propelled and the beanbag and block as inert, and they realized that the hand could have set the beanbag into motion, but the block could not.

The present experiments suggest that infants would look equally at the different- and same-side events if they saw the block move by itself prior to the test trials and thus categorized it as self-propelled. Evidence for this suggestion comes from another experiment conducted by Saxe et al. (2007) with 9.5-month-old infants. Prior to the experiment, the infants were given evidence that a small furry puppet was self-propelled: it jumped slowly across the apparatus floor. At the start of each test event, two screens stood on the apparatus floor on either side of midline. The screens were lowered to reveal two stationary objects: the puppet on one side and a toy train on the other. Next, the screens were raised, and a beanbag was thrown from behind one of the screens. The infants looked reliably longer when the beanbag emerged from the screen with the train than from the screen with the puppet, suggesting that they judged that the puppet could have set the beanbag in motion, but the train could not. Since the puppet had no arms and was about the same size as the beanbag, the infants' responses seemed to reflect an abstract inference that the puppet could have used its internal energy to act on the beanbag rather than a specific belief in the puppet's ability to throw or kick objects; we return to this point in the Discussion of Experiment 4.

5. Experiment 4: can an inert or a self-propelled object remain stable in midair or with inadequate external support?

The preceding experiments suggest that, by 5–6 months of age, infants assume that a self-propelled object can use its internal energy to control its motion in several different ways: it can initiate its motion, it can alter the direction of its motion, and it can resist efforts to set it into motion. Experiment 4 asked whether 6.5-month-old infants also believe that a self-propelled object can use its internal energy to remain stable when released without adequate external support.

The point of departure for this experiment came from investigations of infants' responses to support events. Prior research with <u>inert</u> objects (e.g., Baillargeon, Needham, & DeVos, 1992; Dan, Omori, & Tomiyasu, 2000; Hespos & Baillargeon, 2008; Li, Baillargeon, & Needham, 2006; Needham & Baillargeon, 1993; Yuan & Baillargeon, 2008) suggests that, by about 3 months of age, infants (1) expect an object to fall when released in midair; (2) expect an object to be stable when held by a hand (presumably because the hand can exert an external force on the object to keep it from falling); and (3) have no clear expectation as to whether an object should be stable or fall when released in contact with another object. By about 4.5–5.5 months of age, infants identify type of contact as a support variable: they now expect an object to be stable when released on top of, but not against the side of, another object. By about 6.5 months of age, infants identify another support variable, proportion of contact: they now expect an object to be stable when released on another object if half or more of the supported object's bottom surface rests on the supporting object. In contrast, prior research with <u>self-propelled</u> objects (e.g., Leslie, 1984a) suggests that young infants may <u>not</u> expect a self-propelled object to fall when in midair.

In one experiment, Leslie (1984a) habituated 7-month-old infants to one of several different filmed events back-projected on a movie screen. At the start of one event, a hand grasped a doll resting on a table; the hand lifted the doll and carried it off screen, exiting at the top left corner of the screen. In another event, the hand was separated from the doll by a short gap. Other events were similar to the first two except that the hand was replaced with a box. For present purposes, the key finding was that the infants looked about equally at all of the events during the habituation trials, suggesting that they were not surprised to see a novel self-propelled object move in midair.

This conclusion is consistent with findings from myriad experiments in the infancy literature—on object completion, object individuation, and physical reasoning, in particular—that have presented infants, for reasons of methodological convenience, with events involving self-propelled objects moving in midair (e.g., Bremner et al., 2005; Johnson, 2004; Johnson et al., 2003; Kellman & Spelke, 1983; Kochukhova & Gredebäck, 2007; Slater et al., 1996; Spelke, Kestenbaum, et al., 1995). Had the

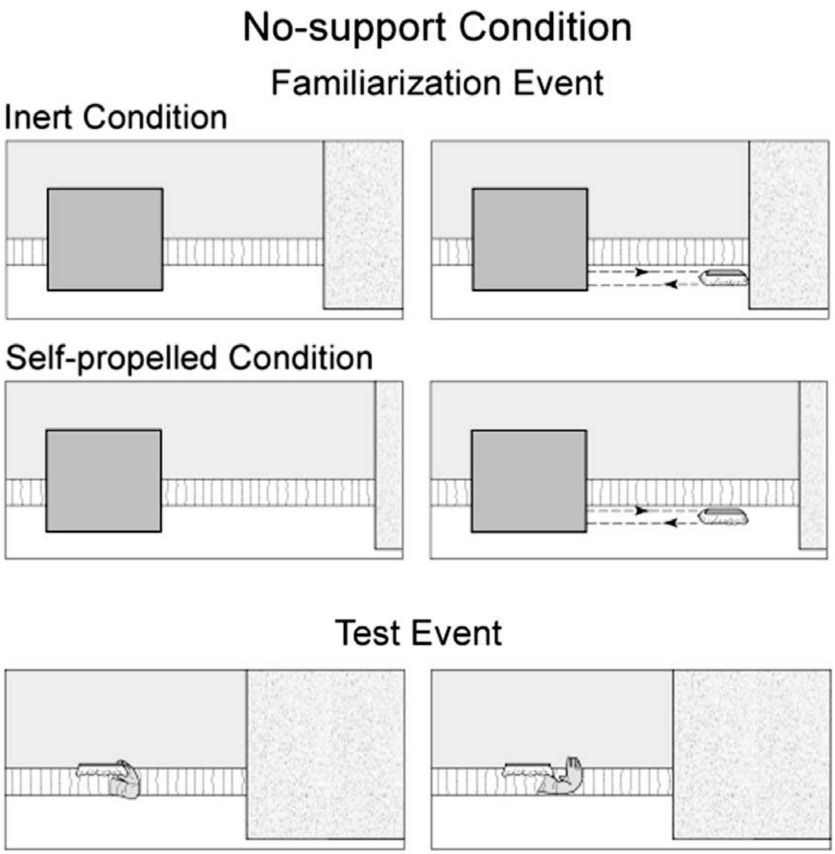

Fig. 7. Schematic drawing of the familiarization and test events in the no-support condition of Experiment 4.

infants in these experiments been surprised to see the objects move in this manner, the results of the experiments would have been consistently negative; the fact that they were not suggests that young infants realize that at least some self-propelled objects require no external support to move in midair. Experiment 4 examined this issue more directly, and asked whether 6.5-month-old infants would expect an inert but not a self-propelled box to fall when released in midair or within adequate external support.

The infants were assigned to an inert or a self-propelled condition and saw the same familiarization event as in Experiment 3: the box emerged from behind a large screen, travelled a short distance to the right, and then reversed direction either on its own (self-propelled condition) or after hitting the wall partition (inert condition). Next, half the infants in each condition saw a test event in which the experimenter's gloved hand held the box in midair; the hand released the box, which then remained stationary (no-support event; see Fig. 7). The other infants saw an event in which the hand held the box with either 1/6 or 1/3 of its bottom surface supported on a platform; once again, the hand released the box, which remained stationary (partial-support event; see Fig. 8).

As in Experiment 3, we expected that during the familiarization trials the infants would categorize the box as inert when it reversed direction after hitting the wall partition and as self-propelled when it reversed direction spontaneously. Because at 6.5 months of age infants expect an inert object to fall when released with less than half of its bottom surface supported (e.g., Baillargeon et al., 1992; Hespos & Baillargeon, 2008; Li et al., 2006; Needham & Baillargeon, 1993), the infants in the inert condition should find both the no-support and the partial-support events surprising. In contrast, if the infants

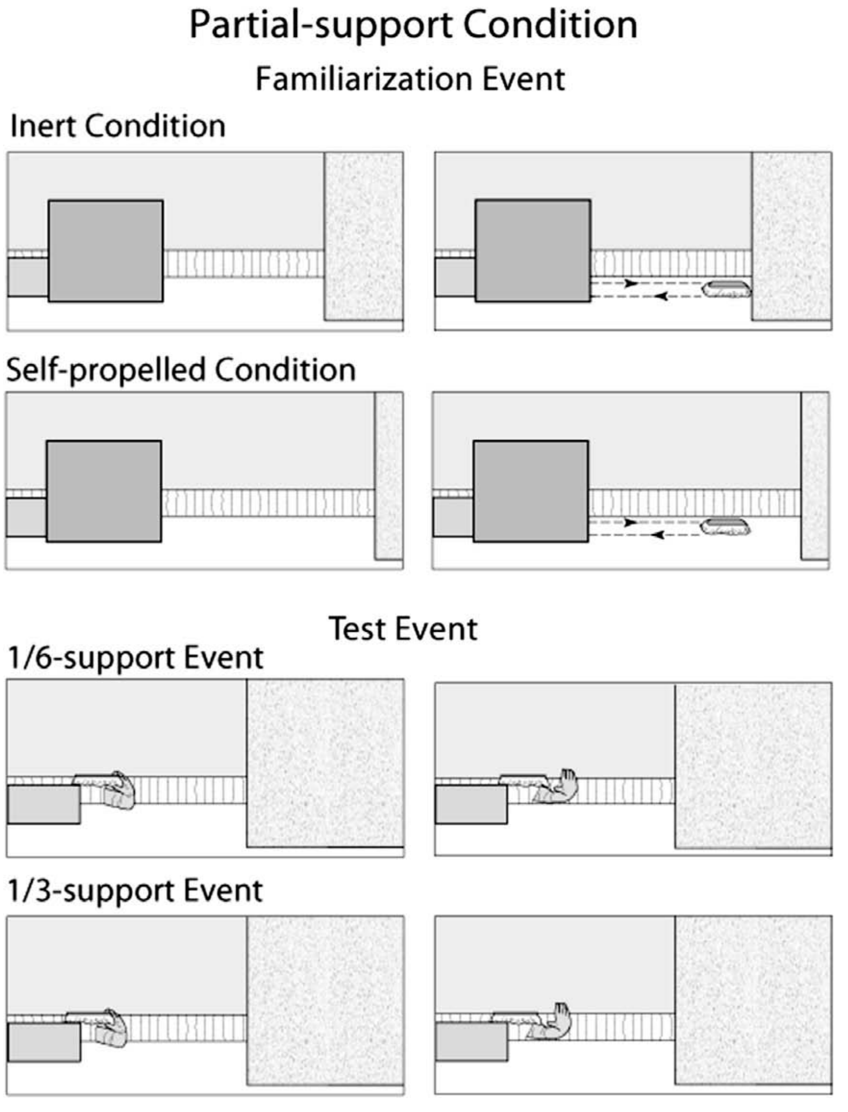

Fig. 8. Schematic drawing of the familiarization and test events in the partial-support condition of Experiment 4.

in the self-propelled condition endowed the box with an internal source of energy (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995) and considered it possible for the box to use its internal energy to keep itself in place, then they might find neither the no-support nor the partial-support event surprising. We thus predicted that the infants in the inert condition would look reliably longer at the no-support and partial-support events than the infants in the self-propelled condition.

5.1. Method

5.1.1. Participants

Participants were 28 healthy term infants, 14 male and 14 female, ranging in age from 6 months, 0 day to 6 months, 21 days (*M* = 6 months, 11 days, *SD* = 6.5 days). Another 14 infants were tested but eliminated, five because they looked for the maximum amount of time allowed (60 s) in both test trials, four because they were fussy (3) or distracted (1), two because their mean looking times during the test trials were more than two *SD*s from the mean of their condition, one because of parental interference, one because of observer difficulties, and one because she required a feeding break during the test session. Half of the infants were randomly assigned to the inert condition (seven male and seven female; *M* = 6 months, 11 days, *SD* = 5.8 days), and half to the self-propelled condition (*M* = 6 months, 12 days, SD = 7.2 days). Within each box condition, half the infants were randomly assigned to the no-support condition, and half to the partial-support condition. In the inert/partial-support condition, four infants saw the 1/3-support event and three saw the 1/6-support event; these numbers were reversed in the self-propelled/partial-support condition.

5.1.2. Apparatus

The apparatus and stimuli used in Experiment 4 were similar to those in Experiment 3 with the following exceptions. During the test trials, the wall partition was placed in a new position: the front surface of the wall partition was extended to 71 cm, so that the side surface now stood 93 cm from the left wall of the apparatus (we refer to this position of the wall partition as the very-near position). Placing the wall partition in this position allowed us to hide the inert or self-propelled box from the infants' view (it was not possible between the familiarization and test trials to quickly detach the box from the motorized system—it was easier to simply roll the box to its reversal point and move the wall partition to the very-near position to hide it).

In the no-support condition, a fake box, identical in appearance to the real box, was positioned 15 cm above the apparatus floor, 28.5 cm from the left wall and 33.5 cm from the front edge of the apparatus. The box was supported at the back (out of the infants' view) by two metal rods. The rods were covered with the same gray granite-patterned contact paper as the back wall; they protruded through the gray fringe at the bottom of the back wall and were attached behind the wall to a heavy wooden base whose front was also covered with gray fringe. During the familiarization trials, the fake box stood above the real box in its starting position and was hidden from the infants by the screen. The fake box was only visible to the infants during the test trials, when the real box was hidden behind the wall partition and the screen was removed.

In the partial-support condition, another fake box, identical in appearance to the real box, was attached to a wooden platform 15 cm high, 28 cm wide, and 59 cm deep; the platform was covered with gray granite-patterned contact paper, to match the back wall, and rested against the left and back walls, 19 cm from the front edge of the apparatus. The box was positioned 14.5 cm from the front of the platform (33.5 cm from the front edge of the apparatus, as in the no-support event), with the left 3.3 cm (1/6-support event) or the left 6.5 cm (1/3-support event) of its bottom surface on the platform. During the familiarization trials, the box and the right portion of the platform were hidden from the infants' view by the screen.

Finally, a small three-sided flap, 2 cm high and 5 cm wide, was cut into the back wall of the apparatus, 37 cm from the left wall and 16 cm above the apparatus floor. The flap allowed the experimenter to monitor her actions on the box during the test trials, but prevented eye contact with the infants.

5.1.3. Events

5.1.3.1. Inert/no-support condition. Familiarization event. The familiarization event shown in the inert/no-support condition was identical to that in the inert condition of Experiment 3: the box emerged from behind the screen, hit the wall partition, and returned behind the screen.

Test event. Prior to the test event, the wall partition was moved from the near to the very-near position, the real box was hidden behind the wall partition, and the familiarization screen was removed. At the start of the event, the experimenter's gloved left hand (in a golden spandex glove) held the right edge of the suspended box. After a 1-s pause, the hand released the box (1 s), which remained stationary. The hand paused in midair about 5 cm from the box, palm facing it (2 s), and then grasped the box again (1 s). Each event cycle thus lasted about 5 s; cycles were repeated until the computer signaled the end of the trial.

5.1.3.2. Inert/partial-support condition. Familiarization event. The familiarization event shown in the inert/partial-support condition was identical to that in the inert/no-support condition, except that a portion of the platform was visible to the left of the screen.

Test event. The test event shown in the inert/partial-support condition was identical to that in the inert/no-support condition, with two exceptions: the platform was present, and the box rested with the left 1/6 (1/6-support event) or the left 1/3 (1/3-support event) of its bottom surface on the platform. As before, the box remained stationary when released by the hand.

5.1.3.3. Self-propelled/no- and partial-support conditions. The familiarization and test events shown in the self-propelled/no- and partial-support conditions were identical to those in the inert/no- and partial-support conditions, with one exception: during the familiarization trials, the wall partition stood in the far position, and the box appeared to reverse direction spontaneously.

5.1.4. Procedure

The procedure used in Experiment 4 was similar to that in Experiment 3. The infants first saw the familiarization event appropriate for their box condition (inert or self-propelled) on six successive trials. Next, the infants saw the test event appropriate for their support condition (no- or partial-support) on two successive trials. Each test trial ended when the infant (1) looked away for one consecutive second after having looked for at least 15 cumulative seconds, or (2) looked for 60 cumulative seconds without looking away for one consecutive second. The 15-s minimum value corresponded to three event cycles and was chosen to ensure that the infants had ample opportunity to observe that the box remained stationary when released. Interobserver agreement during the familiarization and test trials was measured for 27 of the 28 infants and averaged 90% per trial per infant.

Two preliminary analyses were conducted. The first tested whether the infants in the partial-support condition responded similarly (as expected) to the 1/6- and 1/3-support events. The infants' looking times during the two test trials were averaged and compared by means of a 2×2 ANOVA with box condition (inert or self-propelled) and support event (1/6- or 1/3-support) as between-subjects factors. The main effect of support event was not significant, $F(1,10) = 0.14$, nor was the interaction between box condition and support event, $F(1,10) = 0.30$. Planned comparisons confirmed that, in each box condition, the infants responded similarly whether they were shown the 1/6- or the 1/3-support event (inert: 1/6-support event, $M = 37.4$, $SD = 13.7$, 1/3-support, $M = 38.4$, $SD = 13.2$, $F(1,10) = 0.01$; self-propelled: 1/6-support, $M = 27.8$, $SD = 11.7$, 1/3-support, $M = 22.1$, $SD = 4.0$, $F(1,10) = 0.42$). The data were therefore collapsed across support event in subsequent analyses.

The other preliminary analysis tested for possible effects of sex, as in the previous experiments. The data were compared by means of a $2 \times 2 \times 2$ ANOVA with sex, box condition (inert or self-propelled), and support condition (no- or partial-support) as between-subjects factors. The analysis revealed no significant interaction among sex, box condition, and support condition, $F(1,20) = 0.47$; the data were therefore collapsed across sex in subsequent analyses.

5.2. Results

5.2.1. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and analyzed by means of a 2×2 ANOVA with box condition (inert or self-propelled) and support condition (no- or partial-support) as between-subjects factors. The main effects of box condition, $F(1,24) = 0.24$, and support condition, $F(1,24) = 0.30$, were not significant, nor was the interaction between box condition and support condition, $F(1,24) = 0.06$. These results suggested that the infants in the four experimental groups tended to look equally during the familiarization trials (inert/no-support: $M = 26.5$, $SD = 8.1$; inert/partial-support: $M = 30.1$, $SD = 11.2$; self-propelled/no-support: $M = 29.8$, $SD = 9.2$; self-propelled/partial-support: $M = 31.1$, $SD = 16.6$).

5.2.2. Test trials

The infants' looking times during the two test trials (see Fig. 9) were averaged and analyzed in the same manner as the familiarization data. Only the main effect of box condition was significant,

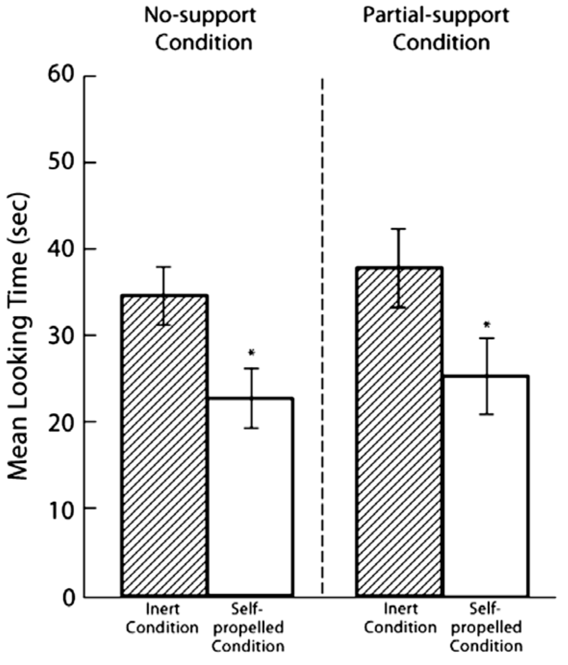

Fig. 9. Mean looking times of the infants in Experiment 4 during the test trials. Error bars represent standard errors. A star (∗) indicates $p < .05$.

$F(1,24) = 10.61$, $p < .005$. Planned comparisons revealed that (1) in the no-support condition, the infants in the inert condition ($M = 34.9$, $SD = 9.0$) looked reliably longer than those in the self-propelled condition ($M = 22.9$, $SD = 9.1$), $F(1,24) = 5.04$, $p < .05$, $d = 1.3$; and (2) in the partial-support condition, the infants in the inert condition ($M = 38.0$, $SD = 12.3$) again looked reliably longer than those in the self-propelled condition ($M = 25.4$, $SD = 9.1$), $F(1,24) = 5.58$, $p < .05$, $d = 1.2$. Non-parametric Wilcoxon rank-sum tests confirmed the results of the no-support ($W = 35$, $p < .05$) and partial-support ($W = 36$, $p < .05$) conditions.

5.3. Discussion

The infants in the inert condition looked reliably longer than those in the self-propelled condition when shown either the no-support or the partial-support test event. These results suggest three conclusions. First, as in Experiment 3, the infants categorized the box as self-propelled when it reversed direction spontaneously and as inert when it did not. Second, the infants in the inert condition were surprised that the box remained stable in midair (no-support event) or with only a small portion of its bottom surface on the platform (partial-support event). This finding is consistent with prior evidence that by 6.5 months of age infants expect an object to fall when released with less than half of its bottom surface supported (e.g., Baillargeon, 1995; Baillargeon et al., 1992; Hespos & Baillargeon, 2008). Finally, the infants in the self-propelled condition were not surprised that the box remained stable either in midair or with only a small portion of its bottom surface supported. This result again is consistent with prior findings that young infants are not surprised when self-propelled objects move in midair (e.g., Bremner et al., 2005; Johnson, 2004; Kellman & Spelke, 1983; Kochukhova & Gredebäck, 2007; Leslie, 1984a; Slater et al., 1996; Spelke, Kestenbaum, et al., 1995).

Together, the preceding results suggest that young infants expect an object to fall when released in midair and realize this fall can be stopped in two ways: (1) by a solid surface that blocks the object's path (as we saw in Experiment 2, the solidity principle dictates that an object cannot pass through another object), or (2) by a force, either internal or external, that halts the object's displacement. This analysis predicts that, for young infants, a self-propelled box might be able to use its internal energy not only to keep itself in midair, as in Experiment 4, but also to "hold" another object. Recent findings support this prediction (Li et al., 2006). In one experiment, 4.5- to 5.5-month-old infants were given evidence that a large box was self-propelled (self-propelled condition) or were given no such evidence (inert condition). During test, an experimenter's gloved hand placed a small inert object against the midsection of the box, a short distance above the apparatus floor, and then released it; the inert object remained stable when released. Only the infants in the inert condition showed surprise at this event, suggesting that the infants in the self-propelled condition considered it possible for the self-propelled box to use its internal energy to exert a force on the inert object so as to keep it from falling to the apparatus floor.

5.3.1. Kinds of explanations

The results of Experiment 4 and of Li et al. (2006) may seem particularly surprising to readers. How could infants possibly think that a self-propelled box could hover in midair or "hold" an inert box in place?

As adults, we clearly know a great deal more than infants do about the physical structures and processes that might allow a self-propelled object to hover in midair or to "hold" another object in place. Compared to adults', infants' reasoning thus appears highly abstract and divorced of most mechanistic details. This conclusion is strongly reminiscent of Keil's (1995) suggestion that our concepts are "embedded in theory-like structures which owe their origins to a small but diverse set of fundamental modes of construal...one key part of these early modes of construal may be more general expectations...[that] exist before any specific explanation or detailed intuitive theory, and thus indicate kinds of explanations rather than any particular explanation" (pp. 260–261). In line with Keil's suggestion, we would argue that the infants in our experiments are offering kinds of explanations, rather than specific or detailed explanations, for the actions of the self-propelled objects they observe.

6. Experiment 5: can an inert or a self-propelled object disappear when behind an occluder?

The results of Experiments 1 through 4 indicate that 5- to 6.5-month-old infants hold different expectations for some but not other physical events involving inert and self-propelled objects. If infants categorize a novel object as inert, they are surprised if it spontaneously reverses its motion, remains stationary when hit or pulled, or remains stable when released in midair; if infants categorize the object as self-propelled, they find none of these outcomes surprising. On the other hand, whether infants categorize a novel object as inert or as self-propelled, they are surprised if it appears to pass through an obstacle. These results are consistent with the proposal, put forth in the Introduction, that (1) infants endow self-propelled but not inert objects with an internal source of energy (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995), and (2) infants hold different expectations for physical events involving inert and self-propelled objects when they judge that an application of internal energy could bring about different outcomes, but not otherwise. In our final experiment, we sought additional evidence for this second claim, under conditions where the outcomes that could and could not be explained by an application of energy were more similar. To this end, in Experiment 5 we compared infants' responses to occlusion events involving an inert or a self-propelled object.

Experiment 5 built on two bodies of experimental findings. One body concerned another corollary of the principle of persistence (e.g., Baillargeon, 2008; Baillargeon, Li, et al., 2009), the continuity principle, which states that objects exist and move continuously in time and space (e.g., Spelke, 1994; Spelke, Phillips, et al., 1995). Numerous experiments have shown that infants aged 2.5 months and older recognize that an object, whether inert or self-propelled, cannot magically appear or disappear, nor can it magically move from one location to another without traveling the distance between them (e.g., Aguiar & Baillargeon, 1999; Aguiar & Baillargeon, 2002; Ahmed & Ruffman, 1998; Baillargeon, DeVos, & Graber, 1989; Baillargeon & Graber, 1988; Luo & Baillargeon, 2005b; Spelke, Kestenbaum, et al., 1995; Wilcox et al., 1996; Xu & Carey, 1996). The other body of findings involved experiments showing that, when confronted with events that seem to violate the continuity principle, infants are

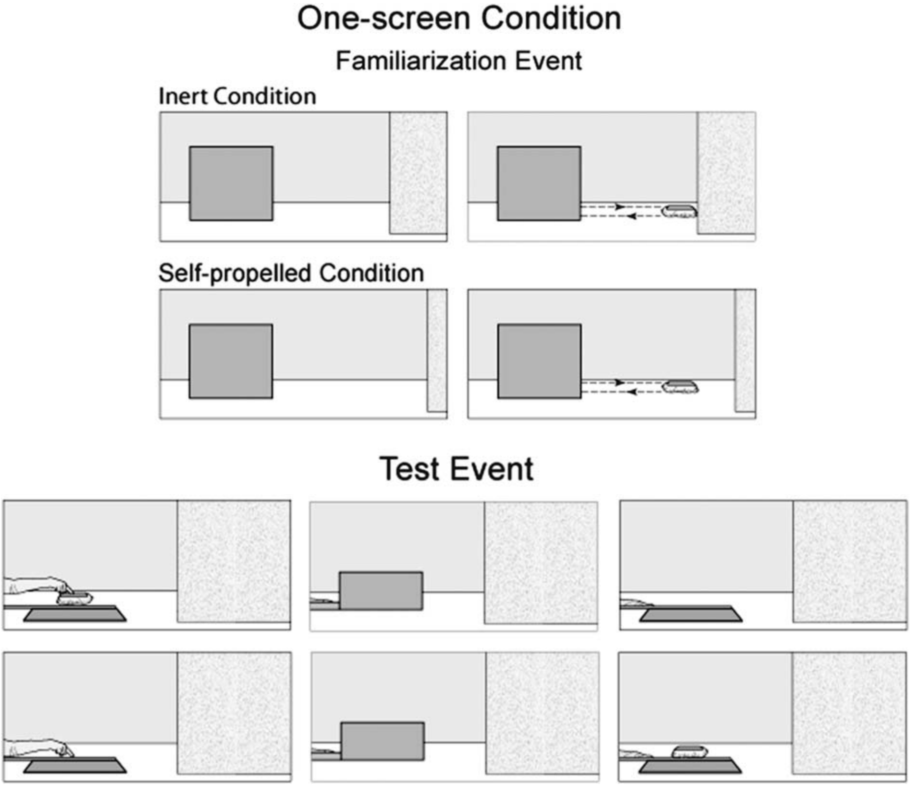

Fig. 10. Schematic drawing of the familiarization and test events in the one-screen condition of Experiment 5.

sometimes able to generate explanations for these violations, typically by inferring the presence of additional objects in the events (e.g., Aguiar & Baillargeon, 2002; Spelke, Kestenbaum, et al., 1995; Xu & Carey, 1996). For example, when a self-propelled toy mouse disappears at the left edge of a screen and reappears at the right edge without appearing in a large opening at the bottom of the screen, infants aged 3.5 months and older typically assume that two mice are involved in the event, one traveling to the left and one to the right of the screen (Aguiar & Baillargeon, 2002). Furthermore, if the screen is first lowered to reveal one mouse and one small screen slightly larger than the mouse, infants assume that the second mouse must have been hidden behind the small screen at the start of the event (Aguiar & Baillargeon, 2002). The present research built on these findings and asked whether 6-month-old infants would be surprised (1) if an inert but not a self-propelled box disappeared from behind a screen, when a second, adjacent screen provided the self-propelled box with an alternative hiding place, and (2) if an inert or a self-propelled box disappeared from behind a screen, when no other screen was present.

The infants were assigned to an inert or a self-propelled condition and they saw the same familiarization event as in Experiments 3 and 4. During test, half the infants in each condition saw a one-screen event (see Fig. 10), and half saw a two-screen event (see Fig. 11). In both events, the box rested on the apparatus floor, and a gloved hand pointed to its top surface. Next, a screen was raised to hide the box. After a pause, the screen was lowered to reveal that the box had disappeared; the hand pointed to the space previously occupied by the box. The screen was raised and, after a pause, was lowered to reveal that the box had reappeared. The only difference between the one- and the two-screen event was that in the latter event a second screen stood to the right of the box. When raised, the first screen occluded the left edge of the second screen, making it possible for the self-propelled box to surreptitiously slip behind it.

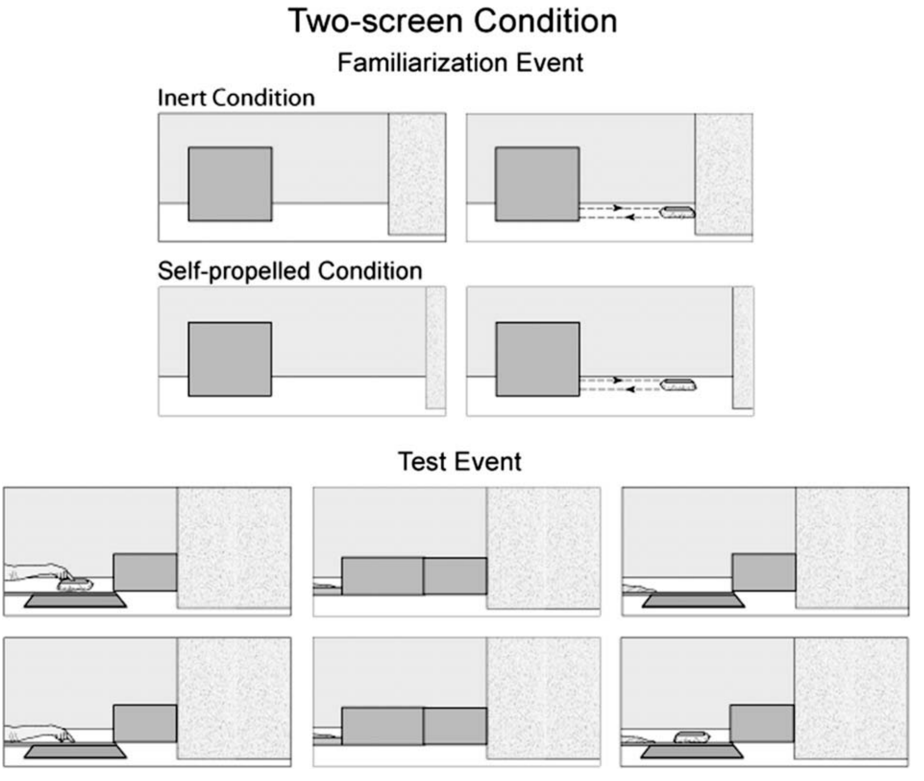

Fig. 11. Schematic drawing of the familiarization and test events in the two-screen condition of Experiment 5.

We reasoned that if 6-month-old infants respond differently to physical events involving an inert or a self-propelled object only when they judge that an application of internal energy can bring about different outcomes, then two predictions followed. First, only the infants in the inert condition should find the two-screen event surprising but the infants in the self-propelled condition should not, because they could infer that the box was using its internal energy to move behind the second screen when it "disappeared" and to return behind the first screen when it "reappeared". Second, the infants in both the inert and the self-propelled conditions should find the one-screen event surprising, because no application of internal energy could allow the self-propelled box to alternately disappear and reappear. We thus expected that, in the self-propelled condition, the infants who saw the one-screen event would look reliably longer than those who saw the two-screen event; and that in the inert condition the infants would look equally, and equally long, whether they saw the one- or the two-screen event.

6.1. Method

6.1.1. Participants

Participants were 28 healthy term infants, 14 male and 14 female, ranging in age from 5 months, 21 days to 6 months, 20 days (*M* = 6 months, 3 days, *SD* = 8.5 days). Another five infants were tested but eliminated, three because they looked for the maximum amount of time allowed (60 s) on both test trials, and two because they were fussy (1) or distracted (1). Half the infants were randomly assigned to the inert condition (six male and eight female; *M* = 6 months, 3 days, *SD* = 7.6 days), and half to the self-propelled condition (*M* = 6 months, 3 days, *SD* = 9.6 days). Within each box condition, half the infants saw the one-screen event, and half saw the two-screen event.

6.1.2. Apparatus

The apparatus and stimuli used in Experiment 5 were similar to those in Experiment 4, with the following exceptions. The opening at the bottom of the back wall of the apparatus (previously filled with gray fringe) was filled with foam board covered with the same gray granite-patterned contact paper as the back wall, except for an opening 15 cm high and 35 cm wide located 22 cm from the left wall. This opening was filled with a trap door that consisted of a piece of soft rubber material topped with gray granite-patterned contact paper.

During the test trials, the real box used in the familiarization trials was hidden behind the wall partition, placed for this purpose in the very-near position. At the start of each test trial, a fake box identical in appearance to the real box stood in the same position as the real box at the start of each familiarization trial. A wooden stick, 1 cm in diameter and covered with black contact paper (to match the apparatus floor), was affixed to the back of the box, out of the infants' view. To make the box disappear, a secondary experimenter opened the trap door in the back wall of the apparatus, grasped the stick, and surreptitiously removed the box; these actions were reversed to make the box reappear.

In the one-screen event, a foam board screen was centered 15.5 cm in front of the fake box, 16 cm from the left wall. The screen was 20 cm high, 44.5 cm wide, 0.5 cm thick, and was covered with green contact paper. It was mounted on a cardboard handle 4 cm high and 0.5 cm thick, covered with the same green contact paper as the screen, and fastened to the floor of the apparatus by Velcro. The handle extended to the left of the screen and out of the apparatus through a window 56 cm high and 52 cm wide in the left wall of the apparatus; the window was filled with an off-white muslin curtain. Outside of the window, the primary experimenter rotated the handle to raise and lower the screen. The primary experimenter also used the window to introduce her right hand (in a golden spandex glove) into the apparatus.

In the two-screen event, a second foam board screen was positioned to the right of and 7.5 cm behind the first screen, with its right edge against the wall partition. The screen was 20 cm high, 34 cm wide, and 0.5 cm thick, covered with green contact paper, and supported at the back by a metal stand. The left 1.5 cm of the second screen was hidden by the first screen, so it was in principle possible for the self-propelled box to move unobserved from the first to the second screen.

6.1.3. Events

6.1.3.1. Inert/one-screen condition. Familiarization event. The familiarization event shown in the inert/one-screen condition was identical to that in the inert condition of Experiment 3: the box emerged from behind the screen, hit the wall partition (in the near position), and returned behind the screen.

Test event. Prior to the test trials, the familiarization screen was removed, the wall partition was moved to the very-near position, the real box was hidden behind the wall partition, the fake box was placed in the usual position at the left end of the slit, and the rotating screen was fastened to the apparatus floor in front of the box. At the start of the event, the screen lay flat on the apparatus floor, so that the box was visible behind it. The primary experimenter's right hand emerged from the window in the left wall of the apparatus and rested palm down on the apparatus floor, with the tips of its fingers 9 cm to the left of the box. After a 1-s pause, the primary experimenter touched the center of the box's top surface with her right index finger (1 s). The primary experimenter then used her left hand (out of sight) to raise the screen and thus to hide the box (1 s). Next, the primary experimenter returned her right hand to its resting position on the apparatus floor (1 s) and paused for 1 s. While the screen was held upright, the secondary experimenter used the trap door to quickly remove the box from the apparatus. The primary experimenter then lowered the screen (1 s), to reveal no box, paused for 1 s, and then pointed to the space previously occupied by the box (1 s). Next, she raised the screen (1 s), returned her right hand to its resting position (1 s), and paused (1 s). While the screen was upright, the secondary experimenter returned the box to its initial position on the apparatus floor. Finally, the primary experimenter lowered the screen (1 s) to reveal the box. Each event cycle thus lasted about 12 s; cycles were repeated until the computer signaled the end of the trial (see below).

6.1.3.2. Inert/two-screen condition. The familiarization and test events shown in the inert/two-screen condition were identical to those in the inert/one-screen condition, except that the second screen was added to the right of the first screen in the test trials.

6.1.3.3. Self-propelled/one- and two-screen conditions. The familiarization and test events shown in the self-propelled/one- and two-screen conditions were identical to those in the inert/one- and two-screen conditions, except that the wall partition stood in the far position during the familiarization trials, so that the box appeared to reverse direction spontaneously.

6.1.4. Procedure

The procedure used in Experiment 5 was similar to that in Experiment 4. The infants first saw the familiarization event appropriate for their box condition (inert or self-propelled) on six successive trials. Next, the infants saw the test event appropriate for their screen condition (one- or two-screen) on two successive trials. Each test trial ended when the infant (1) looked away for one consecutive second after having looked for at least 15 cumulative seconds, or (2) looked for 60 cumulative seconds without looking away for one consecutive second. The 15-s minimum value was chosen to ensure that the infants had the opportunity to observe that the box alternately disappeared and reappeared. Interobserver agreement during the familiarization and test trials was measured for 26 of the 28 infants and averaged 90% per trial per infant.

Preliminary analysis of the infants' looking times during the test trials revealed no significant interaction among box condition, screen condition, and sex, $F(1,20) = 0.02$, the data were therefore collapsed across sex in subsequent analyses.

6.2. Results

6.2.1. Familiarization trials

The infants' looking times during the six familiarization trials were averaged and analyzed by means of a 2×2 ANOVA with box condition (inert or self-propelled) and screen condition (one- or two-screen) as the between-subjects factor. The main effects of box condition, $F(1,24) = 0.51$, and screen condition, $F(1,24) = 0.57$, were not significant, nor was the interaction between box condition and screen condition, $F(1,24) = 0.53$. These results suggested that the infants in the four experimental groups looked about equally during the familiarization trials (inert/one-screen: $M = 37.5$, $SD = 11.8$; inert/two-screen: $M = 31.1$, $SD = 7.1$; self-propelled/one-screen: $M = 31.2$, $SD = 12.7$; self-propelled/two-screen: $M = 31.1$, $SD = 12.9$).

6.2.2. Test trials

The infants' looking times during the two test trials (see Fig. 12) were averaged and analyzed in the same manner as the familiarization data. The main effect of screen condition, $F(1,24) = 5.44$, $p < .05$, and the interaction between box condition and screen condition, $F(1,24) = 6.55$, $p < .025$, were both significant, but the main effect of box condition was not, $F(1,24) = 0.49$. Planned comparisons indicated that, in the self-propelled condition, the infants who saw the one-screen event ($M = 45.3$, $SD = 11.7$) looked reliably longer than those who saw the two-screen event ($M = 27.5$, $SD = 6.1$), $F(1,24) = 11.97$, $p < .0025$, $d = 1.9$; in the inert condition, in contrast, the infants looked about equally whether they were shown the one-screen ($M = 38.5$, $SD = 12.2$) or the two-screen ($M = 39.4$, $SD = 6.9$) event, $F(1,24) = 0.03$, $d = -0.1$. Non-parametric Wilcoxon rank-sum tests confirmed the results of the self-propelled ($W = 34$, $p < .025$) and inert ($W = 51$, $p > .20$) conditions.

Additional planned comparisons revealed that, when shown the one-screen event, the infants in the inert and self-propelled conditions looked about equally, $F(1,24) = 1.73$, $p > .20$, $d = 0.6$; however, when shown the two-screen event, the infants in the inert condition looked reliably longer than those in the self-propelled condition, $F(1,24) = 5.31$, $p < .05$, $d = 1.8$. Non-parametric Wilcoxon rank-sum tests again confirmed the results obtained with the one-screen ($W = 43$, $p > .20$) and two-screen ($W = 33$, $p < .025$) events.

6.3. Discussion

The infants in the self-propelled condition looked reliably longer when shown the one- as opposed to the two-screen event; in contrast, the infants in the inert condition looked about equally, and equally long, at the two test events. These results suggest that, during the familiarization trials, the

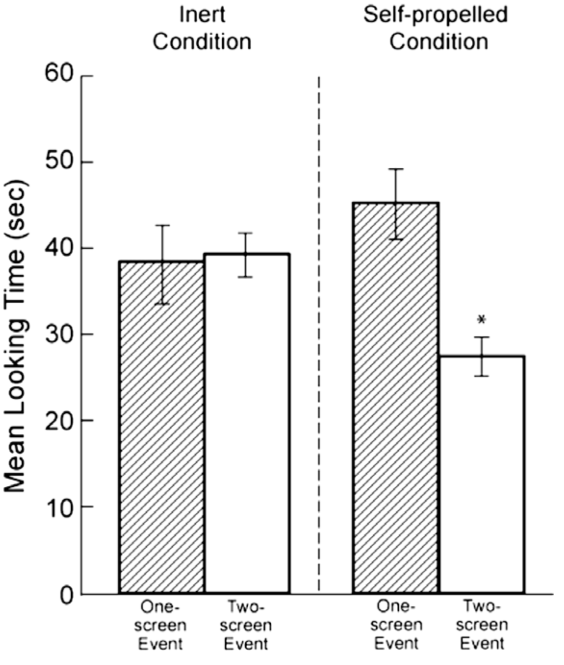

Fig. 12. Mean looking times of the infants in Experiment 5 during the test trials. Error bars represent standard errors. A star (*) indicates $p < .05$.

infants attended to the box's reversal: as in Experiments 3 and 4, the infants categorized the box as self-propelled when it reversed direction spontaneously, and as inert when it reversed direction only after hitting the wall partition. During the test trials, the infants in the inert condition detected the continuity violation in the one- and two-screen events: in each case, they were surprised that the box inexplicably disappeared and reappeared. In contrast, the infants in the self-propelled condition found the one- but not the two-screen event surprising, because they were able to generate an explanation for the latter event. When the box "disappeared", the infants inferred that it had used its internal energy to slip behind the second screen; when it "reappeared", they inferred that it had again used its internal energy to slip back to its original position.

The results of Experiment 5 thus provide additional support for the proposal that (1) infants endow self-propelled but not inert objects with an internal source of energy (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995), and (2) infants hold different expectations for physical events involving inert and self-propelled objects when they reason that an application of internal energy could bring about a different outcome (as in the two-screen event), but not otherwise (as in the one-screen event).

Finally, the results of Experiment 5 also confirm and extend prior evidence that young infants are sometimes able to generate an explanation when shown an event that appears to violate the continuity principle (e.g., Aguiar & Baillargeon, 2002; Spelke, Kestenbaum, et al., 1995; Xu & Carey, 1996). In these experiments, infants inferred the presence of an additional, identical object in the event; in Experiment 5, infants inferred the occurrence of an invisible displacement.

6.4. Links to prior findings: persistence, self-propelled objects, and humans

The present results may also have implications for a report by Kuhlmeier et al. (2004), adapted from an experiment by Spelke, Kestenbaum, et al. (1995), which challenges the notion that infants expect all physical objects to persist, as they are, in time and space. In one condition (box condition), 5-

month-old infants were habituated to a videotaped event in which a self-propelled box slid back and forth across a room, briefly passing behind two door-sized screens placed some distance apart; the box never appeared in the gap between the screens. During test, the screens were removed, and the infants saw two test events: in one, a single box moved back and forth across the room (one-object event); in the other, two boxes moved back and forth in a manner consistent with the habituation event (two-object event). Infants in another condition (human condition) saw similar habituation and test events, except that the self-propelled box was replaced with a woman walking across the room; the woman and her twin, in identical clothes, were involved in the two-object event. The results suggested that the infants in the box condition viewed the one-object event as surprising, whereas those in the human condition viewed neither event as surprising. The authors concluded that at 5 months of age infants apply the continuity principle to self-propelled inanimate objects but not to humans, suggesting that they do not view humans as physical objects.

The results of the self-propelled condition in Experiment 5 suggest another possible interpretation of the human condition data (for other interpretations, see Rakison & Cicchino, 2004). If young infants can posit invisible displacements to make sense of apparent continuity violations, then the habituation event in the human condition was open to two different explanations (which could have been generated by the same or by different infants). One explanation, as in the box condition, was that two different women were involved in the event. The other explanation was that a single woman left and reentered the room through hidden doorways in the wall behind the screens. After all, infants have a great deal of experience watching adults (though not self-propelled boxes) leave and enter rooms through doors that are open or ajar; the fact that the screens were door-sized may have helped remind the infants of these familiar experiences, leading them to posit invisible displacements. In this view, the infants in the human condition thus looked equally at the one- and two-object test events because both events were consistent with possible explanations for the habituation event.

Additional support for the notion that infants view humans as physical objects comes from experiments that have focused on the solidity principle, which as we saw earlier is another corollary of the principle of persistence. Baillargeon et al. (1990) showed 5.5-month-old infants a display in which a toy stood on the left (unexpected event) or right (expected event) side of a barrier; infants in another condition saw a display in which a toy stood under (unexpected event) or on the right side of (expected event) a clear cover. Next, a screen hid the display, and a human hand reached behind the right edge of the screen and immediately reappeared holding the toy. The infants in each condition looked reliably longer at the unexpected than at the expected event, suggesting that they realized that the hand could not have reached through the barrier or cover to retrieve the toy. Similarly, Saxe et al. (2006) recently presented 5-month-old infants with events in which a human hand and arm reached past a screen to become visible on the far side of the screen; a barrier stood in (unexpected event) or out (expected event) of the path of the hand behind the screen. The infants looked reliably longer at the unexpected than at the expect event, suggesting that they realized that the hand could not have moved through the barrier.

In sum, the preceding discussion suggests that, although young infants apply the principle of persistence to human as well as to non-human self-propelled objects, their prior experiences with humans (e.g., seeing them enter and leave rooms by doors) may nevertheless lead them to respond differently to some events involving human and non-human self-propelled objects, as in the experiment of Kuhlmeier et al. (2004).

7. General discussion

The present research built on previous findings that infants distinguish between inert and self-propelled objects and recognize that self-propelled but not inert objects can initiate their own motion (e.g., Kosugi & Fujita, 2002; Kosugi et al., 2003; Kotovsky & Baillargeon, 2000; Saxe et al., 2005; Saxe et al., 2007; Spelke, Phillips, et al., 1995; Woodward et al., 1993). Our research extended these findings in two ways: it examined infants' responses to several different physical events involving an inert or a self-propelled object; and in each case it used the same box as the inert or self-propelled object, to eliminate possible confounds due to incidental differences between the objects.

In our experiments, 5- to 6.5-month-old infants were surprised if the inert but not the self-propelled box reversed direction spontaneously (Experiment 1); remained stationary when hit or pulled (Experiments 3 and 3A); remained stable when released in midair or with inadequate support from a platform (Experiment 4); and disappeared when behind one of two adjacent screens (Experiment 5; the second screen provided the self-propelled box with an alternative hiding place). In contrast, infants were surprised to see either the inert or the self-propelled box pass through an obstacle (Experiment 2) or disappear when behind a single screen (Experiment 5).

These results support the proposal that infants endow self-propelled objects with an internal source of energy (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995). The infants in the present research had never seen our self-propelled box, nor, presumably, any object quite like it. Yet, from observing the box's behavior in one context, they immediately were able to form expectations about its behavior in other contexts. Thus, after observing that the box could begin to move on its own, the infants were not surprised if it reversed direction on its own; after observing that the box could reverse direction on its own, they were not surprised if it remained stationary when hit or pulled, if it remained stable when released without proper external support, or if it moved to a different hiding place when out of sight. We can readily make sense of this constellation of expectations if we assume, in line with the internal-energy hypothesis, that upon observing the box's behavior in the first context, the infants inferred that it possessed an internal source of energy, which it could use to control its motion in the same or other contexts.

The present results also suggest that young infants' reasoning about self-propelled objects is at first extremely naive: their notion of internal energy is little more than an abstract and general "kind explanation" lacking most mechanistic details (e.g., Keil, 1995; Wilson & Keil, 2000). Thus, the infants in Experiments 3 and 3A believed that the self-propelled box could use its internal energy to withstand the substantial force exerted by the hand; the infants in Experiment 4 believed that the self-propelled box could use its internal energy to remain perfectly stable in midair; and recall also that the infants tested by Li et al. (2006) believed that the self-propelled box could use its internal energy to "hold" an inert object against its midsection, without grasping it in any visible way. With development, infants no doubt learn more and more about the mechanical constraints at work in these various events (e.g., what variables affect how great an external force a self-propelled object can withstand?), so that the primitive expectations revealed here are progressively revised or supplanted by more realistic ones.

7.1. Infants' physical reasoning: basic ontological dimensions for categorizing objects

According to the account of infants' physical reasoning we have proposed elsewhere (e.g., Baillargeon, Li, Luo, & Wang, 2006; Baillargeon, Li, et al., 2009; Wang & Baillargeon, 2008), when infants watch a physical event, their physical-reasoning system builds a specialized representation of the event, termed a physical representation. When building this representation, infants typically begin by including the basic information about the event (with experience, infants also come to include variable information, as they learn which variables are relevant for predicting specific events' outcomes). This basic information encompasses both spatiotemporal and identity information. The spatiotemporal information specifies how many objects are involved in the event (up to some limit; e.g., Cheries, Wynn, & Scholl, 2006; Feigenson & Carey, 2005), and how their arrangement changes as the event unfolds. The identity information specifies what kinds of objects are involved in the event (when the spatiotemporal information is ambiguous, the identity information can also help specify how many objects are involved in the event). In previous work, we have argued that one of the basic ontological dimensions infants use to categorize objects has to do with the distribution of closed and open surfaces in the objects: infants routinely specify whether objects are closed, open at the top to form containers, open at the bottom to form covers, or open at both ends to form tubes (e.g., Baillargeon, 1995; Hespos & Baillargeon, 2001b; Wang & Baillargeon, 2006; Wang et al., 2005; for a recent review, see Baillargeon et al., 2009). Thus, when watching a ball being lowered inside a container, young infants may not include information about the size, shape, pattern, or color of the ball and container in their physical representation of the event—but they will include the information that the ball is a closed object, and the container a container (e.g., Hespos & Baillargeon, 2001a; Hespos & Baillargeon, 2001b; Ng & Baillargeon, 2006).

The present research extends this account by suggesting that another basic ontological dimension infants use to categorize objects—and thus part of the basic identity information infants routinely include in their physical representations of events—is whether the objects are inert or self-propelled. This view predicts that infants younger than those in the present experiments may also respond differently to events involving inert and self-propelled objects. This prediction was recently confirmed in experiments with 2.5- to 4 month-old infants (Wu, Luo, & Baillargeon, 2006; Yuan & Baillargeon, 2008; for a recent review, see Baillargeon, Wu, et al., in press).

One noteworthy consequence of the account proposed here is that it calls into question the commonly-held notion that infants interpret physical events in terms of a single category of objects, namely, physical objects. From a very early age, infants appear to categorize objects in terms of a few basic ontological dimensions, and to hold different expectations for at least some events involving these different object categories.

7.2. Self-propelled objects and agents

In the last section, we suggested that the distinction between inert and self-propelled objects is one embedded in the skeletal causal framework that makes possible infants' physical reasoning. When infants see an object move, their physical-reasoning system is designed to "attend to information about sources of energy and their consequences" (Gelman et al., 1995, p. 151). But is this view correct?

An alternative possibility is that infants do not in fact possess a concept of self-propelled object: rather, they possess a concept of <u>agent</u>. According to this view, infants would divide up physical objects into two broad categories: inert objects (e.g., cups, balls, rocks, and apples) and agents (e.g., people, animals, cars, and novel self-propelled boxes). To explain why agents do not always act in the same manner as inert objects in physical events, infants would appeal to psychological rather than to physical causes. From this perspective, the present findings would suggest that by 5 months of age infants recognize that (1) agents, like all other physical objects, are subject to the principle of persistence (e.g., they cannot pass through obstacles or magically disappear into thin air), but otherwise (2) agents do what they want to do. Thus, the reason why the self-propelled box in our experiments reversed course, remained stationary when hit, or remained suspended in midair was not that it possessed an internal source of energy that enabled it to do so, but rather that it <u>wanted</u> to do so. With experience, infants would come to realize that, due to physical constraints, the powers of agents are often limited: for example, humans cannot fly like birds or run up trees like squirrels even if they would like to (e.g., Luo & Baillargeon, 2009).

The alternative possibility just described depends on two critical assumptions: one is that infants can view a non-human self-propelled object as an agent, and the other is that infants view all self-propelled objects as agents. As explained below, recent evidence supports the first but not the second of these assumptions.

7.2.1. Non-human self-propelled objects can be agents

Recent research indicates that infants aged 3 months and older can view non-human self-propelled objects as agents (e.g., Csibra, 2008; Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Gergely, Nádasdy, Csibra, & Bíró, 1995; Johnson et al., 2007; Johnson et al., 2008; Kamerawi, Kato, Kanda, Ishiguro, & Hiraki, 2005; Luo, 2009; Luo & Baillargeon, 2005a; Shimizu & Johnson, 2004; Surian, Caldi, & Sperber, 2007). For example, in a task adapted from a seminal experiment conducted by Woodward (1998) with a human agent, 5-month-old infants first received orientation trials in which they saw a small box move back and forth across the center of an apparatus floor (Luo & Baillargeon, 2005a). Next, two objects were placed on either side of the box, object-A near the right wall of the apparatus and object-B near the left wall. During the familiarization trials, the box moved toward and stopped against object-A. Following these trials, the positions of the two objects were reversed, and the infants received test trials in which the box approached and stopped against object-A (old-object event) or object-B (new-object event).

As in Woodward's (1998) experiment, the infants looked reliably longer at the new- than at the old-object event. This and control results suggested that the infants viewed the box as an agent: during familiarization, they attributed to the box a particular disposition, a preference for object-A over object-B; during test, they expected the box to maintain this preference and hence to form the goal of approaching object-A in its new position. The infants were therefore surprised in the new-object event when the box approached object-B instead. These results provided the first experimental demonstration that infants as young as 5 months of age can attribute mental states such as dispositions and goals to a non-human self-propelled object—and hence that they can view such an object as an agent. Luo (2009) recently extended these results to 3-month-old infants.

7.2.2. Not all non-human self-propelled objects are agents

Although infants can view non-human self-propelled objects as agents, as we just saw, they do not necessarily do so. Recent research by Csibra, Johnson, and their colleagues (e.g., Csibra, 2008; Johnson et al., 2007; Johnson et al., 2008; Shimizu & Johnson, 2004) suggests that for a non-human self-propelled object to be viewed as an agent, it must provide (what infants construe as) unambiguous evidence that it is acting intentionally—in other words, that perceptions, dispositions, goals, and/or other mental states are causing its actions. From this perspective, an object that follows the same fixed path over and over again (think of a ceiling fan going round and round, or of the sun following the same arc daily across the sky), or an object whose behavior appears random (think of a tree branch swaying in the wind), is unlikely to be viewed as an agent. Only self-propelled objects whose actions appear intentional, or guided by mental states, can be agents.

In an important series of experiments, Johnson and her collaborators (Johnson et al., 2007; Shimizu & Johnson, 2004) tested 12-month-old infants in a task similar to that of Luo and Baillargeon (2005a). During habituation, an oval-shaped "blob" covered with bright green fiberfill stood near the front of the apparatus; at the back of the apparatus were two toys, object-A on one side and object-B on the other. During each habituation trial, the blob approached and stopped against object-A. During the test trials, the toys' positions were reversed, and the blob approached either object-A (old-object event) or object-B (new-object event). At the start of each habituation and test trial, the blob's front-to-back axis was aligned with the object it approached during the trial. The infants looked about equally at the new- and old-object events, suggesting that they viewed the blob as a self-propelled object—since it initiated its motion in plain sight—but not as an agent: because the blob followed the same fixed path in every habituation trial, it gave no clear evidence that it was acting intentionally.

In contrast to this negative result, infants looked reliably longer at the new- than at the old-object event in two key conditions. In one, instead of being aligned with object-A at the start of each habituation trial, the blob faced a position midway between the two toys and "turned" toward object-A—as though making a choice—before approaching it. In the other condition, the blob participated in a scripted "conversation" with an experimenter prior to the habituation trials; the experimenter spoke English and the blob responded with a varying series of beeps. The positive results in these conditions suggested that the infants now viewed the blob as an agent; they interpreted its behavior in habituation as revealing a preference for object-A, they expected this preference to be maintained across trials, and they were therefore surprised in test when the blob approached object-B. Interestingly, negative results were obtained (1) if the blob remained silent when the experimenter spoke (suggesting that it was not merely seeing the experimenter talk to the blob that led the infants to view it as an agent); or (2) if the blob beeped as before but the experimenter remained silent and stared at the floor (suggesting that it was not merely observing that the box could produce varying beeps that led the infants to view it as an agent; apparently, variable self-generated behavior, if it appears random, does not constitute evidence of agency). Finally, in converging experiments using a "gaze-following" measure, Johnson et al. (2008) found that, after observing the blob turn toward one of two targets, 14- to 15-month-olds tended to turn in the same direction if the blob first participated in a conversation with an experimenter (agent condition), but not if it beeped and the experimenter remained silent (non-agent condition).

Together, these results suggest that (1) infants view a self-propelled object as an agent only if its actions appear intentional or guided by mental states, and (2) infants are sensitive to several types of evidence for intention. A blob that beeps contingently in a conversation with an experimenter gives evidence of intention because it appears to be detecting and responding to the utterances of the experimenter (a blob that beeps on its own could be beeping randomly). Similarly, a blob that first turns toward and then approaches a toy gives evidence of intention because it appears to be adjusting its behavior so as to achieve a particular goal, namely, that of contacting its preferred toy (in the same manner, recall that the self-propelled box in Luo and Baillargeon (2005a) moved back and forth across the center of the apparatus in the orientation trials but approached and stopped against object-A in the familiarization trials, suggesting that it was modifying its behavior so as to contact its preferred object).

Recent work by Csibra (2008) points to yet another type of evidence for intention: choosing different means across trials to achieve the same goal. This research built on work by Kamerawi et al. (2005), which itself was designed to extend earlier work by Csibra, Gergely, and their colleagues (e.g., Csibra et al., 1999; Gergely et al., 1995). Kamewari et al. habituated 6.5-month-old infants to a videotaped event in which an agent moved around an obstacle to reach a target. The agent was either a human, a human-like robot, or a self-propelled box. In test, the obstacle was removed, and the agent followed the same path as before (old-path event) or moved in a straight line to the target (new-path event). Infants looked reliably longer at the new- than at the old-path event when the agent was the human or the robot, but not when it was the self-propelled box. Csibra (2008) replicated this last, negative result and suggested that, because the box followed the same fixed path in every habituation trial, infants were not certain whether it was an agent. To test this idea, Csibra again habituated 6.5-month-olds to events in which a self-propelled box moved around an obstacle to reach a target; however, the box now moved around the right or the left end of the obstacle on alternate habituation trials. Results were positive, suggesting that this slight variation in means was sufficient to lead the infants to view the box as an agent; as a result, they attributed to the box the goal of reaching the target, they expected the box to pursue this goal efficiently in every trial, and they were surprised in test when the box followed the same path as in habituation: with the obstacle removed, this circuitous path now represented an inefficient way to reach the target.

The results summarized above, together with those of the present research, suggest that self-propelled object and agent are different concepts for infants; the concept of self-propelled object is embedded in the skeletal causal framework that makes possible their physical reasoning (e.g., Baillargeon, Li, et al., 2009; Baillargeon et al., 2006; Carey & Spelke, 1994; Gelman et al., 1995; Leslie, 1994; Spelke, 1994; Wang & Baillargeon, 2008; Wellman & Gelman, 1997), and the concept of agent is embedded in the skeletal causal framework that makes possible their psychological reasoning (e.g., Gergely & Csibra, 2003; Johnson, 2000; Leslie, 1995; Luo, 2009; Luo & Baillargeon, 2007; Premack & Premack, 1995; Scott & Baillargeon, in press; Surian et al., 2007). Of course, when faced with a novel object that gives evidence of being both self-propelled and agentive, infants may bring to bear both concepts simultaneously—we return to this point in the next section. However, when a self-propelled object gives no evidence that it is behaving intentionally, infants may simply attend to the object's internal energy and its consequences. This analysis suggests that, in at least some of the present experiments, the infants did not view the self-propelled box they were shown as an agent. For example, the infants in Experiments 1 and 2 would have had little basis to view the box as an agent since it followed the same fixed path in every trial as it moved back and forth across the apparatus. The present analysis also predicts that infants might view an inert object as an agent if it somehow provided evidence that it behaved intentionally (e.g., think of the magical mirror in the fairy tale "Snow White", or of the magical ring in the book and movie "Lord of the Rings"). We recently tested this prediction using a box that never moved but that beeped in a conversation with an experimenter; across a series of experiments, 14-month-old infants gave evidence that they viewed the box as both inert and agentive—in other words, as an inert agent (Wu & Baillargeon, 2007).

7.3. Self-propelled objects and animals

In the last section, we considered the possibility that infants possess not a concept of self-propelled object, as we have suggested throughout this article, but rather a concept of agent. We reviewed recent evidence that infants in fact possess both concepts; they appreciate that self-propelled objects may not be agents and that agents may not be self-propelled. In this section, we focus on a different concept, that of animal. Could the infants in the present experiments have viewed our self-propelled box as an animal? To answer this question, we first need to consider whether young infants possess a concept of animal and, if so, what is the nature of this concept. There is a vast and controversial literature focusing on the development of infants' and preschoolers' knowledge about animals (e.g., for reviews, see Carey, 1999; Gelman & Opfer, 2002; Inagaki & Hatano, 2002; Mandler, 2004; Quinn, 2002; Rakison, 2003; Subrahmanyam et al., 2002); here we simply mention two possibilities.

7.3.1. Animals as self-propelled agents

Mandler (in press) recently suggested that infants "divide the world of objects into animals and nonanimals" (p. 5), and that their concept of animals is composed of two conceptual primitives: objects "that start motion by themselves" and objects "that interact contingently with other objects from a distance" (p. 13). According to Mandler, conceptual primitives are "innate, in the sense that they are activated by innate attentional proclivities" (p. 22); they correspond to "pieces of spatial information, especially movements in space" (p. 7); and they are used by a Perceptual Meaning Analysis mechanism to redescribe (reduce and recode) perceptual patterns into global and skeletal concepts such as that of animal.

As is no doubt clear from previous sections of this article, our position differs from that of Mandler (in press, 2004) in that we construe infants' concepts of self-propelled object and agent not as spatial forms but as abstract constructs embedded in their causal frameworks. This issue aside, however, we find intriguing Mandler's suggestion that for infants animals are essentially self-propelled agents. Thus, depending on the evidence presented to them, infants might view some objects as self-propelled but not agentive, other objects as agentive but not self-propelled, and yet other objects are both self-propelled and agentive; these last objects would be animals.

From an evolutionary standpoint, it would not be surprising if infants were strongly biased to attend to self-propelled agents; after all, for our distant ancestors, these objects would typically have been either predators or prey—in other words, a potential threat or a potential treat (for an interesting discussion, see Barrett, 2005). Thus, we might expect infants to be especially attuned to these objects and to rapidly learn about their surface properties, parts, motions, and behaviors, and indeed there is a great deal of experimental evidence to this effect (e.g., Arterberry & Bornstein, 2002; Mandler & McDonough, 1996; Mandler & McDonough, 1998; Pauen, 2002; Quinn & Eimas, 1996; Quinn & Eimas, 1997; Rakison, 2003; Rakison & Poulin-Dubois, 2001; Rakison & Poulin-Dubois, 2002; Smith & Heise, 1992; Träuble et al., 2006). To give just one example, in an experiment by Träuble et al. (2006), 7-month-old infants first received a trial in which they saw two objects standing apart and motionless on an apparatus floor: a ball and a novel toy animal with a face and a furry body. In the next trial, the ball and animal were intertwined and moved together in a self-propelled manner. In the final trial, the two objects again stood apart and motionless. The infants looked reliably longer at the animal on the last than on the first trial, suggesting that they (1) believed that the animal was more likely than the ball to be self-propelled; (2) assumed that the animal was the cause of the two objects' joint motions; and (3) anticipated that the animal might move again.

7.3.2. Animals as something more than self-propelled agents?

According to the possibility mentioned above, animals would initially be those objects that are identified as both self-propelled and agentive. From this perspective, infants' concept of animal would thus represent the union of two other concepts, one physical and the other psychological, and it would have no biological overtones. With experience, children's concept of animal would gradually take on such overtones until it finally became embedded in an adult-like biological theory (e.g., Carey, 1985; Carey, 1995; Carey, 1999).

However, another possibility is that, upon observing that an object is both self-propelled and agentive, infants immediately hold additional expectations about the object that are quasi-biological in nature. What might such expectations be? One possible candidate is an expectation that a self-propelled agent's internal energy is likely to be tied to (or to emanate from) its material composition. Subrahmanyam et al. (2002) reviewed evidence that young children distinguish between animals, moving machines, sentient machines, and inert objects. According to these authors, for an object to be classified as an animal, it is not sufficient that it be self-propelled and agentive: it must also be composed of the "right kind of stuff", namely, "biological stuff" (p. 347). This is because young children's reasoning about animals is informed by domain-specific causal principles which allow them to appreciate ‘‘the connection between biological matter and animate motion” (p. 346). Another possible candidate is an expectation that a self-propelled agent is likely to have insides. Previous research suggests that by 3–5 years of age children already expect animals and artifacts to have different insides (e.g., Gelman, 1990; Gelman & Gottfried, 1996; Gottfried & Gelman, 2005; Simons & Keil, 1995). Here we are focusing on a simpler notion—that infants simply expect self-propelled agents to have insides. If they do (but have no clear expectations about the insides of self-propelled objects that are not agents or about the insides of agents that are not self-propelled), then it might suggest that infants' concept of animal is not, in fact, reducible to that of self-propelled agent.

It should be emphasized that the two possible expectations just discussed may at first be conceptually separate. Gottfried and Gelman (2005) found that 4-year-olds who were interviewed about unfamiliar animals and machines were reliably more likely to answer yes when asked if the animals, as opposed to the machines, used their ‘‘own energy” to move (see also Gelman & Gottfried, 1996; Massey & Gelman, 1988; Morris, Taplin, & Gelman, 2000). At the same time, the children were equally likely to answer yes when asked if the animals or the machines used ‘‘their own insides” to move. These and other results suggested that young children do not initially view an animal's insides as causally relevant to its motion; their notion of energy is a highly abstract concept, ‘‘free from a notion of insides” (p. 140) and ‘‘independent of any internal part” (p. 155).

Do infants possess expectations about self-propelled objects that go beyond their separate properties of being self-propelled and agentive? We are beginning experiments to address this question. As for the question we raised earlier—did the infants in the present research view the novel self-propelled box they were shown as an animal—the preceding discussion suggests that they might not have done so. If an animal is (at the very least) a self-propelled agent, and if (as discussed earlier) the infants were generally unlikely to view the box as an agent, then it follows that they were also unlikely to view it as an animal.

7.4. Concluding remarks

In the present research, 5- to 6.5-month-old infants were not surprised when a self-propelled box reversed direction spontaneously, remained stationary when hit or pulled, remained stable when released in midair or with inadequate external support, or disappeared when behind one of two adjacent screens. Infants were surprised, however, when a self-propelled box appeared to pass through an obstacle or disappeared when behind a single screen. This evidence suggests two broad conclusions. First, consistent with the proposals of Gelman and Leslie (e.g., Gelman, 1990; Gelman et al., 1995; Leslie, 1994; Leslie, 1995), infants appear to endow self-propelled objects with an internal source of energy. Second, although infants' notion of energy is certainly primitive and provides only an abstract ‘‘kind of explanation” (e.g., Keil, 1995) for the actions of self-propelled objects, it still makes possible rich inferences in new contexts. Thus, young infants who observe a novel box spontaneously reverse direction, and who therefore endow it with internal energy, may not understand exactly how this energy works—but they immediately recognize that it may enable the box to resist moving when hit or to resist falling when released in midair.

More generally, the findings reported here, together with the research we have reviewed on infants' concepts of agent and animal, are helping us better understand the complex and dynamic conceptual apparatus that underlies infants' remarkable expectations about objects and events.

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