YOUNG INFANTS' EXPECTATIONS ABOUT SELF-PROPELLED OBJECTS

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INTRODUCTION

Investigations of the development of infants' physical reasoning over the past 20 years have revealed that even young infants possess expectations about physical events (for recent reviews, see Baillargeon, Li, Luo & Wang, 2006; Baillargeon, Li, Ng, & Yuan, in press). These findings, which come increasingly from both violation-of-expectation tasks (e.g., Aguiar & Baillargeon, 1999, 2002; Hespos & Baillargeon, 2001b; Lécuyer & Durand, 1998; Luo & Baillargeon, 2005b; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wang, Baillargeon, & Paterson, 2005; Wilcox, Nadel, & Rosser, 1996) and action tasks (e.g., Goubet & Clifton, 1998; Hespos & Baillargeon, 2006, 2008; Hofstadter & Reznick, 1996; Hood & Willatts, 1986; Kochukhova, & Gredeback, 2007; Ruffman, Slade, & Redman, 2005; von Hofsten, Kochukova, & Rosander, 2007), support the notion that infants are born with an abstract, unconscious, physical-reasoning system, which provides them with a shallow causal framework for making sense of the displacements and interactions of objects and other physical entities (e.g., Baillargeon et al., in press; Carey & Spelke, 1994; Gelman, 1990; Keil, 1995; Leslie, 1994; Premack & Premack, 1995; Spelke, 1994; Wellman & S. A. Gelman, 1997).

Gelman (1990; Gelman & Spelke, 1981; Gelman, Durgin, & Kaufman, 1995; Subrahmanyam, Gelman, & Lafosse, 2002) and Leslie (1984a, 1994, 1995; Leslie & Keeble, 1987) have suggested 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 watching a novel object begin to move or change direction, infants' 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 an internal source of energy. 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.

Do young infants distinguish between inert and self-propelled objects? Do they endow self-propelled objects with internal energy? One way to address these questions empirically is to examine whether young infants hold different expectations for physical events involving inert and self-propelled objects. Upon observing that a novel object begins to move on its own, or changes direction on its own, do infants hold different expectations about how the object might behave in various physical events? Are these expectations causally consistent with the notion that the object possesses internal energy it can use to control its motion or that of other objects?

This chapter is organized into two sections. In the first, longer section, we summarize the results of several series of experiments from our laboratory that compared the responses of 2.5- to 6.5-month-old infants 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 each experiment was typically the same novel object. During familiarization, half the infants were given evidence that the object was self-propelled (e.g., it initiated its motion in plain view); the other infants were given no such evidence and so presumably categorized the object as inert. During test, the infants saw new physical events involving the object. The experiments tested whether infants (1) would view the outcomes of some events as surprising when they categorized the object as inert but not when they categorized it as self-propelled, because in the latter case they could infer that the object 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 object as inert or as self-propelled, because they realized that no application of internal energy could have brought about the observed outcomes.

In the second, shorter section of the chapter, we consider what might be the links between the concept of self-propelled object explored here and other key concepts. Are young infants who see a novel object initiate its own motion likely to view it only as a self-propelled object endowed with internal energy—or are they likely to view it as something more? For example, could infants view the object as an agent that can detect its environment and move intentionally in pursuit of goals, or as an animal composed of biological matter? We discuss various characterizations and consider their implications for infants' construal of the novel self-propelled objects studied in this chapter (for additional discussion of these issues, see Shutts, Markson, & Spelke, this volume).

I. INFANTS' EXPECTATIONS ABOUT SELF-PROPELLED OBJECTS

To our knowledge, the first experiment that directly compared infants' responses to physical events involving inert and self-propelled objects was conducted by Woodward and her colleagues (Spelke, Phillips, & Woodward, 1995b; Woodward Phillips, & Spelke, 1993). This experiment examined whether 7-month-old infants believe 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 physical entity. The infants were assigned to an inert or a self-propelled condition. The infants in the inert condition were habituated to a videotaped event involving two different, large (human-sized), wheeled pillars. To start, one pillar stood partly visible at the right edge of a large occluder at the center of the television monitor (events in this and in all other experiments in this chapter are described from the infants' perspective). The second pillar moved into view on the left side of the monitor and disappeared behind the left edge of the occluder; after an appropriate interval, the first pillar 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 pillars moved as before; the only difference between the events had to do with what happened during the previously occluded portion of the pillars' trajectories. In one event (contact event), the moving pillar collided with the stationary pillar and set it in motion; in the other event (no-contact event), the moving pillar stopped short of the stationary pillar, which then set off on its own. The infants in the self-propelled condition saw identical events except that the two pillars were replaced with a man and a woman who walked along the same path as the pillars.

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 tended to look equally at the two events. These and control results suggested three conclusions. First, because there was no clear indication that the pillars 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 not. Second, the infants believed that inert objects can be set in motion only through contact with (and the application of force by) other physical entities, and thus they inferred that one pillar must be colliding with the other behind the occluder. Third, the infants realized that humans are self-propelled objects, and thus they understood that each human could move on its own or as a result of an application of force by the other human.

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. As alluded to earlier, our own experiments attempted to extend these results in several directions. First, they asked whether infants younger than 7 months might also hold such differential expectations. Second, our experiments compared infants' responses to events involving the same novel object, presented either as inert or as self-propelled. One limitation of the results described above is that, because the events involving the pillars and humans were so different, it is difficult to determine what role perceptual differences or prior experiences with humans might have played in the infants' responses. Our approach, in essence, was to compare infants' responses to events involving only pillars (and other like objects such as boxes, cylinders, and balls), to determine what additional expectations infants might hold simply from observing that a pillar was inert or self-propelled. Third, our experiments explored a wide range of physical events. In choosing these events, we considered specific ways in which a self-propelled object might use its internal energy to control its motion or that of other objects. Thus, as described in the following sections, we asked whether young infants would believe that a self-propelled object might use its internal energy (1) to alter the direction of its motion; (2) to change location when out of sight; (3) to change the orientation or position of its parts when out of sight; (4) to remain stationary when hit; (5) to remain stable when released without adequate external support; and finally (6) to "hold" an inert object so as to prevent it from falling.

1. Can a self-propelled object alter the direction of its motion?

The results of Woodward and her colleagues (Spelke et al., 1995b; Woodward et al., 1993) suggested that infants realize that a self-propelled object can initiate its own motion, whereas an inert object cannot (see also Kosugi & Fujita, 2002; Kosugi, Ishida, & Fujita, 2003; Kotovsky & Baillargeon, 2000; Saxe, Tenenbaum, & Carey, 2005; Saxe, Tzelnic, & Carey, 2007). Our first experiment asked whether 5-month-old infants hold different expectations not only for the onset of inert and self-propelled objects' motion, but also for the path they follow once in motion (Luo et al., in press). As adults, we expect an inert object traveling on a horizontal plane to follow a smooth path, without abrupt changes in direction;[1] in contrast, we recognize that a self-propelled object may use its internal energy to change direction at will. 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; in inert objects, abrupt changes in direction cannot be achieved without external impact. Experiment 1 (Luo et al., in press) thus 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 in fact <u>not</u> 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; 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 was removed, the ball rested in the same back left corner as in the habituation event, as though it had performed a 90^{o} turn when under the screen. The infants did not look longer at the nonlinear 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, with no abrupt change in direction.

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 absolute difference), the infants saw the ball at rest in the front or back corner of the indentation (a smaller and perhaps less salient absolute 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 detect path deviations, 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) and sat in front of a large apparatus whose right side was occluded by a large screen. A small box (5 cm high, 19.5 cm wide, and 17 cm deep) was visible on the left side of the apparatus; this box was covered with red felt and had a "skirt" made of white lace that reached the apparatus floor and hid the motorized system that controlled the box's motion back and forth across the apparatus. In the inert condition, an experimenter's gloved hand activated this system by simultaneously hitting the box and a microswitch located next to the box, so that it appeared as though the hand caused the box to move. In the self-propelled condition, the experimenter activated the system by depressing a button on a control panel located under the apparatus floor, so that it appeared as though the box began to move on its own. The box's motion 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.

In the familiarization events shown in the inert condition, the 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 to begin a new event cycle (in all experiments in this chapter, unless otherwise noted, events were repeated until the trial ended). Following familiarization, the screen was removed, and the infants watched a near- and a far-wall test event (here and in all other pertinent experiments in this chapter, order of presentation was counterbalanced). In the near-wall event, 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 and returned to its starting position (although the box appeared to hit the partition and "bounce back", in actuality only its lace skirt contacted the partition; a reverse-switch under the apparatus caused the box to reverse direction). In the far-wall event, the wall partition was placed farther to the right; because the box moved exactly as before, it no longer hit the partition and thus appeared to reverse direction on its own. Since the 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 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., Leslie, 1994, 1995; Luo & Baillargeon, 2005a; Spelke et al., 1995b; Woodward et al., 1993), 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 in plain view.

Furthermore, if at 5 months infants (1) endow self-propelled but not inert objects with internal energy and (2) expect an object to follow a smooth path unless a force—either internal or external to the object—intervenes to bring about an abrupt 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 appeared to reverse direction spontaneously, but not when it reversed direction after hitting the wall partition: this impact provided an external cause for the abrupt change in its 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, and equally short, at the far- and near-wall events.

Results were as predicted: the infants in the inert condition looked reliably longer at the far- than at the near-wall event, whereas those in the self-propelled condition tended to look equally, and equally short, at the two events. These results suggested that the infants in the inert condition (1) categorized the box as an inert object since they received no evidence to the contrary; (2) expected the box to follow a smooth path, with no abrupt deviation, in the absence of external impact; and hence (3) were surprised when it spontaneously reversed direction. In contrast, the infants in the self-propelled condition (1) categorized the box as self-propelled since it initiated its own motion; (2) understood that the box could use its internal energy to alter its path; and hence (3) were not surprised when it spontaneously reversed direction.

Links to other findings: Predictive tracking and reaching

The results of the inert condition in Experiment 1 help reconcile previously discrepant findings in the infancy literature. In contrast to the violation-of-expectation findings of Spelke et al. (1994) described above, 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 et al., 2007; von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998). These contrastive results have sometimes been taken to point to the existence of a 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 the design used by Spelke et al. was perhaps less than optimal and that young infants can demonstrate an expectation that objects follow a smooth path in both violation-of-expectation and 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, consistent with those of Experiment 1, 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 violation-of-expectation 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, 2002; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Bremner et al., 2005; S. P. Johnson, 2004; S. P. Johnson, Amso, & Slemmer, 2003; Kellman & Spelke, 1983; Luo & Baillargeon, 2005a, 2005b; Luo, Baillargeon, Brueckner, & Munakata, 2003; Slater, S. P. Johnson, Brown, & Badenoch, 1996; Spelke, Kestenbaum, Simons, & Wein, 1995a; Wilcox, 1999; Wilcox & Baillargeon, 1998b; 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.

Control findings

One possible objection to our interpretation of the results of the self-propelled condition in Experiment 1 and in Woodward et al. (1993; see also Spelke et al., 1995b) was the following: perhaps the infants were merely confused by the test events they were shown and hence held no specific expectations about their outcomes. This interpretation seemed unlikely: as was just 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 (Luo et al. in press) was conducted to rule out 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 et al., in press), 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. 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, 2003; Baillargeon, 1986, 1987, 1991; Baillargeon, Spelke, & Wasserman, 1985; Baillargeon, Graber, DeVos, & Black, 1990; Baillargeon & DeVos, 1991; Hespos & Baillargeon, 2001a, 2001b; Luo et al., 2003; Saxe, Tzelnic, & Carey, 2006; Sitskoorn & Smitsman, 1995; Spelke et al., 1992; Wang, Baillargeon, & Brueckner, 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. 2) and received familiarization trials identical to those shown in the inert and self-propelled conditions of Experiment 1, respectively, with one exception: in these trials as in all other trials of Experiment 2, the wall partition was always in the far position (with the large screen occluding the right side of the apparatus, the infants in the inert condition could not determine just how far the box traveled behind the screen or what caused it to reverse direction). Next, the familiarization screen was removed, and the infants received two orientation trials in which they were introduced to a large table (table orientation event) and a large block (block orientation event); each rested across the box's path, directly in front of the infants, and was briefly rotated upward to make clear that it extended from the front to the back of the apparatus. Finally, the infants were shown a table and a block test event. In the table event shown in the self-propelled condition, 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 traveled to the right and once more after it reversed direction to return to its starting position (the block used in the block test event had a small tunnel that allowed the box to pass through; 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). The infants in the inert condition saw the same test events except that the box did not initiate its motion: as in the familiarization trials, 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 impact with the wall partition, then the infants in Experiment 2 should respond differentially to the block and table test events. Because even young infants realize that an object, whether self-propelled or not, cannot pass through another object, 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, the infants 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 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.[2]

Results were as predicted: the infants in the self-propelled condition looked reliably longer at the block than at the table event, whereas those in the inert condition looked about equally, and equally long, at the two events.

These results, together with those of Experiment 1, supported the proposal that young infants endow self-propelled objects with an internal source of energy. On the one hand, infants are not surprised when a self-propelled object spontaneously initiates or reverses its motion, because they realize that the object can use its internal energy to do so; on the other hand, infants are surprised when a self-propelled object passes through an obstacle, because they realize that no application of internal energy could allow the object to do so. Infants' expectations about self-propelled objects are thus neither undefined nor arbitrary but appear causally consistent with the notion that self-propelled objects use their internal energy to control their motion.

2. Can a self-propelled object change location when out of sight?

If young infants realize that self-propelled objects can initiate their motion at will, could they posit hidden displacements to make sense of events that would otherwise seem impossible? In particular, could infants infer that a self-propelled object had moved to another hiding location when out of sight, to make sense of a disappearance that would otherwise seem inexplicable? Our next experiment examined this question, and built on two bodies of experimental findings.

One body concerned another corollary of the principle of persistence, the continuity principle, which states that objects exist and move continuously in time and space. 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, 2002; Ahmed & Ruffman, 1998; Baillargeon, DeVos, & Graber, 1989; Baillargeon & Graber, 1988; Luo & Baillargeon, 2005b; Spelke et al., 1995a; 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 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 et al., 1995a; Xu & Carey, 1996). For example, when a self-propelled toy mouse disappears at one edge of a screen and reappears at the other edge without appearing in a large opening at the bottom of the screen, 3.5-month-old infants 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). In Experiment 3 (Luo et al., in press), we presented young infants with an apparent continuity violation: an inert or a self-propelled object magically disappeared when behind a screen. We asked whether infants might infer that the self-propelled object had used its internal energy to move to a different hiding location when the physical lay-out of the apparatus made such an invisible displacement possible. Experiment 3 thus examined whether 6-month-old infants would be surprised (1) if an inert but not a self-propelled object disappeared from behind a screen, when the self-propelled object could have moved to an alternative hiding place, and (2) if an inert or a self-propelled object disappeared from behind a screen, when no alternative hiding place was available.

The infants were assigned to an inert or a self-propelled condition and saw novel familiarization events suggested by 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 apparatus; however, the box was now hidden by a large screen. During the event, the box emerged to the right of the screen, traveled 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 offered unambiguous evidence that the box was self-propelled, since it reversed direction spontaneously. In contrast, the familiarization event shown in the inert condition offered 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.

During test, half of the infants in each condition saw a one-screen event (see Fig.3), and half saw a two-screen event (see Fig. 4). In both events, the box rested on the apparatus floor, and a gloved hand pointed to its top surface; the hand reached into the apparatus through a window in the left wall. Next, a screen was raised and then lowered to reveal that the box had disappeared; the hand pointed to the space previously occupied by the box. Finally, the screen was again raised and lowered to reveal that the box had reappeared, beginning a new event cycle (because the gloved hand rested on the apparatus floor between the screen and the window when the screen was lifted and lowered, it was clear that it could not have surreptitiously removed and replaced the box). 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 move behind it.

Results were as expected: in the self-propelled condition, the infants who saw the one-screen event looked reliably longer than those who saw the two-screen event; in the inert condition, the infants tended to look equally, and equally long, at both events. These results suggested two conclusions. First, the infants attended to the box's reversal during the familiarization trials, and categorized the box as self-propelled when it reversed direction spontaneously, and as inert when it reversed direction only after hitting the wall partition. Second, 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: they inferred that the box used its internal energy to move behind the second screen when it "disappeared", and to return from behind the second screen when it "reappeared".

Test with younger infants

Would infants younger than 6 months also invoke invisible displacements to make sense of continuity violations involving self-propelled but not inert objects? Experiment 4 (Wu, Luo, & Baillargeon, 2006) attempted to address this question and tested 4-month-old infants using a new experimental design. We reasoned that positive findings would suggest that infants as young as 4 months of age already hold different expectations for at least some physical events involving inert and self-propelled objects.

The infants were assigned to an inert or a self-propelled condition (see Fig. 5). The infants in the inert condition faced a wide screen with two closed windows located a short distance apart. In the familiarization trial, an experimenter's gloved hand (which reached into the apparatus through a fringe curtain in the back wall) lifted a red column above the screen, between the two windows. The hand gently tilted the column to the left and right twice, and then lowered it back behind the screen, in the same location as before. Next, the hand performed exactly the same actions with a black ball. The infants in the self-propelled condition saw a similar occlusion event except that the objects now appeared to move by themselves. Each object had a thin stick at its back that protruded through a slit in a cardboard inserted behind the fringe curtain; the experimenter used the stick, out of the infants' view, to move the column and ball as in the inert condition.

Following the familiarization trial, all the infants saw the same one- and two-window test events. In the two-window event, the gloved hand opened the right window in the screen (by pulling a handle that protruded above the screen) to reveal the column, and then closed the window; next, the hand opened the left window to reveal the ball, and then again closed the window. In the one-window event, the hand again opened the right window to reveal the column, but then opened the same window to reveal the ball. The two objects thus appeared in different windows in the two-window event, but in the same window, in alternation, in the one-window event.

Our reasoning was as follows. Prior research on infants' physical reasoning suggests that, by 4 months of age, infants have identified height, width, and shape as occlusion variables, and thus typically include such information in their representations of occlusion events (e.g., Baillargeon & DeVos, 1991; Wang et al., 2004; Wilcox, 1999). Thus, we expected that the infants in Experiment 4 would attend to the differences in height, width, and shape between the column and the ball, and would conclude that two different objects were involved in the familiarization event, even though the objects followed exactly the same path when moving above the screen. Furthermore, given the results of Experiments 1 to 3, we expected that the infants in the inert condition would categorize the objects as inert, since they received no evidence to the contrary; and that the infants in the self-propelled condition would categorize the objects as self-propelled, since they spontaneously altered their motions in plain sight (recall that the objects rose above the screen and then tilted left and right twice before returning behind the screen). Finally, we reasoned that the infants in the inert condition should find the one- but not the two-window test event surprising: whereas the two-window event was consistent with there being two inert objects, a column and a ball, occupying two distinct locations behind the screen, the one-window event involved a continuity violation, since the two objects appeared to magically exchange locations behind the screen. On the other hand, if infants as young as 4 months of age recognize that self-propelled objects can move at will, then the infants in the self-propelled condition might not view either test event surprising: when faced with the one-window event, the infants could infer that the objects surreptitiously exchanged locations when out of sight.

As predicted, the infants in the inert condition looked reliably longer at the one- than at the two-window event, whereas those in the self-propelled condition looked about equally, and equally short, at the events. These results suggested that infants as young as 4 months of age (1) distinguish between inert and self-propelled objects;

(2) endow self-propelled objects with internal energy; and (3) infer that self-propelled objects are engaging in invisible displacements to make sense of occlusion events that would otherwise violate the principle of persistence.

Experiment 5 (Wu, Luo, & Baillargeon, 2008) was designed to provide converging evidence for our interpretation of the results of the self-propelled condition. The experiment examined whether 4-month-old infants would infer that two self-propelled objects (now a multicolored column made of Lego blocks and a green ball) exchanged locations out of view when it was physically possible for the objects to do so, but not otherwise.

The infants faced a wooden vertical frame; each end of the frame was hidden by a screen. Each screen had a tab at its outer top corner, which was held by an experimenter's gloved hand (the experimenter stood behind a window filled with a fringed curtain in the back wall of the apparatus and held the left screen's tab in her right hand and the right screen's tab in her left hand). Each tab could be used to lower the screen to the apparatus floor, in the manner of a drawbridge. The area between the two screens was either closed by a cardboard insert (closed condition) or open (open condition). The infants in the closed condition (see Fig. 6) first saw a one- and a two-screen orientation event designed to introduce them to the motion of the screens. In the two-screen event, the experimenter lowered the right screen to the apparatus floor (to reveal empty space behind it), and then raised it again; next, the experimenter performed the same actions on the left screen (again to reveal empty space). The one-screen event was identical except that the experimenter lowered and raised only the right screen. Next, as in the self-propelled condition of Experiment 4, the infants saw a familiarization event in which the column and ball rose (one at a time) above the center of the frame, tilted gently to the left and right twice, and then returned behind the frame. Finally, the infants saw two test events identical to the one- and two-screen orientation events except that the column and ball were now present. In the two-screen event, the column was revealed behind the right screen and the ball behind the left screen; in the one-screen event, the two objects were revealed behind the right screen, in alternation. The infants in the open condition (see Fig. 7) were tested using the same procedure except that the area between the two screens was open in the orientation and test events (it was closed in the familiarization event, when the column and ball rose above the frame). Although the one-screen test event was possible in the closed condition (the infants could infer that the column and ball exchanged locations when the two screens were raised), it was not possible in the open condition, where the area between the screens remained visible and empty, making it clear that the objects did not exchange locations.

As predicted, the infants in the open condition looked reliably longer at the one- than at the two-screen event, whereas those in the closed condition looked about equally, and equally short, at the events. Together, these results suggested that the infants (1) categorized the column and ball as self-propelled during the familiarization trial; (2) did not find the one-screen event surprising when the area between the screens was closed, because they could then infer that the objects exchanged locations out of sight; but (3) did find the one-screen event surprising when the area between the screens was open, because such an explanation was then not possible; the objects appeared to magically exchange locations, which constituted a continuity violation.

Together, the results of Experiments 3-5 suggest that infants aged 4 months and older believe that self-propelled objects can use their internal energy to move—in or out of view—to new locations. However, these visible and invisible displacements are all expected to be constrained by the continuity principle: like inert objects, self-propelled objects cannot magically disappear, nor can they magically move from one location to another without traveling the distance between them.

Links to other findings: Are humans subject to the continuity principle?

Kuhlmeier, Bloom, and Wynn (2004) reported data (collected with a design adapted from Spelke et al., 1995a) that might be taken to challenge the notion that infants expect all objects, whether inert or self-propelled, to move continuously through time and space, in accordance with the continuity principle. 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 of these and other conditions suggested that the infants in the box condition viewed the one-object event as surprising, whereas the infants in the human condition viewed neither event as surprising. The authors concluded that at 5 months of age infants apply the continuity principle to non-human but not to human self-propelled objects, suggesting perhaps that they do not view humans as physical entities.

However, the results of Experiments 3 to 5 suggest another 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.

3. Can a self-propelled object move or change its parts when out of sight?

Research on object segregation indicates that young infants view contiguous surfaces that move together as connected surfaces that belong to a single object; furthermore, this conclusion holds whether the surfaces are similar or dissimilar in shape, pattern, and color (e.g., Kestenbaum, Termine, & Spelke, 1987; Needham, 1998, 1999, 2000; Spelke, 1988). This research suggested that young infants who saw a novel box with distinct parts move across an apparatus floor would perceive the box and its parts as a single, connected object.

Our next experiments (Wu & Baillargeon, 2006, 2007a, 2008) examined infants' responses to events in which one or more parts of a box moved while the box was briefly hidden. In designing these experiments, we considered three different ways in which parts might move; for ease of communication, we refer to these as changes in location, position, and orientation. A location change is one in which a part moves from one side of the object to another; a position change is one in which a part remains on the same side of the object, but moves up or down; and finally an orientation change is one in which a part preserves its location and position on the object but changes its orientation.

Evidence that infants might discriminate between at least some of these changes came from research by Slaughter and Heron (2004). In one experiment, 12-month-old infants were habituated to pictures of a novel three-dimensional "geobody", which consisted of a large cylindrical red 'torso' with two cylindrical blue 'legs', two cylindrical green 'arms', and a square yellow 'head'. Across pictures, the geobody was shown with its arms and legs in different orientations. During test, the infants were shown scrambled geobodies with their arms and legs either disconnected or moved to different locations (e.g., one arm and one leg were now attached to a different side of the torso, or both arms were attached to the head). The infants dishabituated to these scrambled geobodies, suggesting that they (1) represented which parts were located where on the habituation geobody and (2) discriminated between the orientation changes shown in habituation and the location changes shown in test.

Below, we describe our experiments on orientation, position, and location changes, and conclude with an experiment on appearance changes.

<u>Orientation changes</u>

In Experiment 6 (Wu & Baillargeon, 2006), 5.5-month-old infants were shown an inert or a self-propelled box with two salient parts; during test, while the box was briefly hidden, the orientation of its parts was changed. Our experiments examined whether the infants would view this change as surprising when the box was inert but not when it was self-propelled, because in the latter case they could infer that the box had used its internal energy to reorient its parts (e.g., in the same way that a man might change the orientation of his arms while out of sight).

The infants were assigned to an inert or a self-propelled condition (see Fig. 8) and were shown events involving a blue box with two large rectangular flaps. The flaps were attached to the upper left and right edges of the box and rested against each other at the top, above the box (like two large 'ears' touching each other at the top). The interior and exterior surfaces of the flaps and the top of the box were red and decorated with bright yellow dots. The familiarization trials were modeled after those in Experiment 3 and used the same apparatus. In the <u>self-propelled</u> condition, the wall partition at the right of the apparatus was in its far position; the box emerged to the right of the large screen, traveled to the right a short distance, and then reversed direction on its own to return behind the screen. In the <u>inert</u> condition, the wall partition was in its near position; the box moved as before but now hit the wall partition before reversing direction and returning behind the screen. Following the familiarization trials, all of the infants received a single test trial in which they saw either a no-change or a change event. At the start of each event, the box stood behind a small screen which lay flat on the apparatus floor, near the left wall. The screen was rotated upward to hide the box and, after a pause, was rotated back down again. When revealed, the box was either the same as before (no-change event) or was altered: its flaps had moved apart and now extended on either side of its top surface, parallel to the apparatus floor (change event). The screen was then rotated again, to begin a new event cycle; the box always had its flaps together in the no-change event and had its flaps alternately together and apart in the change event.

In the inert condition, the infants who saw the change event looked reliably longer than those who saw the no-change event; in the self-propelled condition, in contrast, the infants tended to look equally at the two events. Together, these results suggested that 5.5-month-old infants realize that a self-propelled object can use its internal energy not only to control its motion through space, as we saw in previous sections, but also to alter the orientation of its parts. Additional support for this interpretation came from another experiment (Experiment 7) that used a new blue box with a single, jagged flap extending from its upper left edge, parallel to the apparatus floor (see Fig. 9). The lower portion of the flap was red and was decorated with yellow dots; its upper portion consisted of three yellow, triangular projections. In the change test event, the flap was flipped upward to hang above the box (like a large 'tail' extending either behind or above the back of an animal). The results of Experiment 7 were identical to those of Experiment 6, and confirmed that young infants are surprised when the parts of an inert but not a self-propelled object spontaneously change orientation.

Position changes

Our next experiment (Wu & Baillargeon, 2008) examined infants' responses to events in which the parts of a box changed position, rather than orientation, when the box was briefly hidden. As mentioned earlier, by a position change we mean a change in the place where a part is connected to the box: the part remains on the same side of the box but moves up or down. We speculated that, as with orientation changes, young infants might view position changes as surprising for an inert but not a self-propelled box. To young infants with a limited understanding of how connections are made or of how far they can stretch or shift in any direction, it might seem possible for a self-propelled box to use its internal energy to move its parts up or down (e.g., perhaps in the same way that a man can move his shoulders, or his eyebrows, up or down).

Experiment 8 used the same design as Experiments 6 and 7, with a new red box that was decorated with two blue stripes at the bottom and that sported a yellow rectangular flap on either side, parallel to the apparatus floor (see Fig. 9). For half the infants, the flaps were even with the top of the box in the familiarization and the no-change test events and were positioned lower (just above the blue stripes) in the change test event; for the other infants, the reverse was true. Results were identical to those in Experiments 6 and 7: in the inert condition, the infants who saw the change event looked reliably longer than those who saw the no-change event, whereas in the self-propelled condition, the infants looked about equally at the two events. The infants were thus surprised when the inert but not the self-propelled box changed the position of its flaps up or down.

Location changes

As was mentioned earlier, location changes refer to changes in which a part moves to a different side of a box. We speculated that such changes, unlike orientation and position changes, might seem surprising to infants even for a self-propelled box. If infants interpreted a location change as indicating that a part had become disconnected from its initial location on the box and had become reconnected at the new location, then such a change would violate two corollaries of the principle of persistence: the cohesion and boundedness principles (e.g., Spelke, 1990, 1994; Spelke et al., 1995b). These principles state that objects are connected and bounded entities: they cannot spontaneously fragment as they move (cohesion) or fuse with other objects (boundedness). Numerous experiments have shown that infants aged 3 months and older detect violations when objects spontaneously break apart or become connected to other objects (e.g., Kestenbaum et al., 1987; Needham, 1999, 2000; Needham & Baillargeon, 1997; Spelke, 1988; Spelke, Breinlinger, Jacobson, & Phillips, 1993).

In Experiment 9 (Wu & Baillargeon, 2008), 5.5-month-old infants were tested with the same procedure as in the self-propelled condition of Experiments 6-8, using a new red box with two rectangular yellow flaps (see Fig. 9). For half the infants, the flaps were on opposite sides of the box, flush with its top, in the familiarization and the no-change test events, and the right flap moved to a new location a short distance below the left one in the change test event; for the other infants, the reverse was true. Results indicated that the infants who saw the change event looked reliably longer than those who saw the no-change event. For the first time in this series of experiments, infants viewed the change introduced—a part moving from one side of a self-propelled box to the other—as unexpected, as though they realized that no application of internal energy could result in a part becoming disconnected from one location and reconnected at another location.

The results of Experiment 9 extend the results of Slaughter and Heron (2004) mentioned earlier in several ways. First, they suggest that, when shown a simple self-propelled object with two parts, infants as young as 5.5 months of age detect when one of the parts changes location. Second, the results indicate that infants' ability to detect location changes does not depend on the parts being symmetrically distributed; similar results were obtained in Experiment 9 whether the two parts were initially on the same side or on opposite sides of the box. Finally, the results suggest that infants not only detect location changes but view them as unexpected. The infants in Experiments 6-9 looked reliably longer at the change event when the parts of the self-propelled box changed location behind the screen, but not when they simply changed orientation or position. These results suggest that the infants realized that no application of energy could allow a self-propelled object to disconnect a part (a cohesion violation) and reconnect it elsewhere (a boundedness violation).

Appearance changes

Experiment 10 (Wu & Baillargeon, 2007a) examined 5.5-month-old infants' responses to events in which a part of a self-propelled box preserved its orientation, position, and location but changed its appearance (i.e., its size, shape, pattern, and color) while the box was occluded by a screen. We expected that infants would find such a change surprising. According to the principle of persistence (e.g., Baillargeon, 2008; Baillargeon et al., in press), an object, whether inert or self-propelled, cannot magically change its appearance; apples cannot change into bananas, and frogs (no matter what the fairy-tales say) cannot change into princes. Whether infants detect an appearance change in an event depends on (1) whether they have identified the relevant variables (e.g., size, shape, pattern, and color) for the event category involved, and hence (2) whether they include information about these variables in their physical representation of the event (e.g., Wang & Baillargeon, 2006, 2008). Prior research indicates that, by 4.5 months of age, infants have identified height, width, and shape as occlusion variables (e.g., Baillargeon & DeVos, 1991; Wang & Baillargeon, 2006; Wang et al., 2004; Wilcox, 1999) and thus detect appearance changes involving these variables in occlusion events. For example, Wilcox (1999; Wilcox & Baillargeon, 1998a, 1998b) found that infants aged 4.5 months and older are surprised if a self-propelled box changes into a self-propelled ball when passing behind a screen too narrow to hide both objects at once. Experiment 10 built on these results and asked whether infants would realize that not even a part of a self-propelled box could change its appearance while the box was briefly occluded.

Infants were tested with the same procedure as in the self-propelled condition of Experiments 6-8. For half the infants, the box used in the familiarization and the no-change test events was the blue box with the yellow jagged flap from Experiment 7, and the box used in the change test event was a similar blue box with a new flap consisting of a red half circle outlined with light green tape and decorated with dark green stars (see Fig. 9); for the other infants, the reverse was true. In either case, the infants who saw the change event looked reliably longer than those who saw the no-change event, indicating that by 5.5 months of age, infants recognize that a self-propelled box cannot change the appearance of a part. (Because at 5.5 months infants have identified size and shape but not yet pattern and color as occlusion variables, we suspect that the infants in Experiment 10 responded primarily to the impossible change in the size and shape of the box's flap; Wilcox, 1999).

Persistence revisited

One important theme to emerge from the research reported in this and the preceding sections is that even young infants recognize that the principle of persistence applies somewhat differently to self-propelled and inert objects. Infants recognize that, when behind a screen, a self-propelled object may use its internal energy to move to an alternative hiding place (Experiments 3-5), to change a part's orientation (Experiments 6 and 7), or to change a part's position (Experiment 8). At the same time, infants view as impossible other changes that cannot be explained by an application of internal energy, such as disappearing into thin air (Experiment 3), changing a part's location (Experiment 9), or changing a part's appearance (Experiment 10). For inert objects, in contrast, infants construe all of the changes listed above as impossible.

These findings suggest two conclusions. First, when it comes to distinguishing between possible and impossible changes, what the principle of persistence essentially states is that objects can undergo no uncaused change. Because a self-propelled object can use its internal energy to change the orientation of its parts, such a change is deemed possible; because an inert object cannot spontaneously reorient its parts, such a change is deemed impossible and is flagged as a persistence violation. Second, infants adopt a conservative stance in judging what changes might be caused or uncaused in the world. If the handle of a teacup changes orientation behind a screen, infants do not assume that some causal process unknown to them must have effected the change; only when they possess some hint about the causal process that could have produced a change (e.g., an application of internal energy) do they view the change as possible. Of course, because of their limited physical knowledge, infants are very often wrong about the nature, operation, or details of these causal processes; we return to this point in a later section.

Links to further results: Expecting self-propelled objects to move

In all of the experiments discussed so far, infants aged 4 to 6 months categorized the novel object they were shown as self-propelled based on what might be called behavioral information: the object either initiated its motion in plain view or reversed direction on its own. Prior research suggests that infants aged 7 months and older can also use featural information to determine which objects are likely to be self-propelled and which are not (e.g., Golinkoff, Harding, Carlson, & Sexton, 1984; Johnson, Slaughter, & Carey, 1998; Markson & Spelke, 2006; Poulin-Dubois, Lepage, & Ferland, 1996; Poulin-Dubois & Shultz, 1988, 1990; Rakison, 2003; Rakison & Poulin-Dubois, 2001, 2002; Spelke et al., 1995b; Traeuble, Pauen, Schott, & Charalampidu, 2006; Woodward et al., 1993). Indeed, we have already discussed evidence to this effect: recall that the 7-month-old infants tested by Woodward and her colleagues (Spelke et al., 1995b; Woodward et al., 1993) viewed the man and woman who walked back and forth behind the occluder as self-propelled. Additional evidence comes from research by Traeuble et al. (2006). In one experiment, 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.

These results give rise to an interesting question concerning some of the experiments discussed in previous sections. To see why, consider the infants in Experiments 6 to 8 who saw the no-change event in the test trial. Given the results of Traeuble et al. (2006), we might ask whether the infants who believed the box was self-propelled tended to look longer than those who believed the box was inert, because they expected the box to move again. Of course, such a prediction might not hold in our experiments, for two reasons: first, the screen in front of the box was continually raised and lowered throughout the trial, so that the infants might have been preoccupied with other aspects of the event; second, the effect observed by Traeuble et al. might be found primarily in situations where infants are presented with two objects standing side by side, one inert and one self-propelled. Nevertheless, to get at this question, we pooled the data from Experiments 6 to 8 and compared the responses to the no-change test event of the infants in the inert and self-propelled conditions. No reliable difference was found, suggesting that our experiments did not create an appropriate context to observe the effect reported by Traeuble and her colleagues.

Markson and Spelke (2006) reported findings that might at first appear consistent with those of Traeuble et al. (2006) but inconsistent with our own. In a series of experiments, 7-month-old infants saw two familiarization events in which they were presented with 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 two findings. First, as in Traeuble et al., the infants looked reliably longer at the self-propelled object, as though anticipating that it would move again. Second, this last 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 many experiments reported in this chapter where infants readily learned whether the objects shown in the familiarization trials were self-propelled or not. However, Shutts et al. (this volume) recently suggested that extraneous factors might have contributed to the different 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; a shape that flipped over backwards several times). As predicted, and consistent with the findings reported in this chapter, infants now readily learned which object was inert and which was self-propelled in all pairs of objects.

4. Can a self-propelled object remain stationary when hit?

The evidence reviewed in the previous sections suggests that young infants believe that a self-propelled object can use its internal energy to spontaneously move itself or its parts, either in or out of view. In this section and the next, we examine whether young infants also believe that a self-propelled object can use its internal energy to resist moving.

The point of departure for Experiment 11 (Luo et al., in press) came from investigations of infants' responses to collision events. Prior research with inert objects (e.g., Baillargeon, 1995; Kotovsky & Baillargeon, 1998, 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, infants take into account the size (or weight) of the first object, and expect the second object to be displaced farther when hit by a larger (or heavier) as opposed to a smaller (or lighter) object. Finally, by about 9 months, infants begin to take into account the size (weight) of the second object, and now expect a very large (heavy) object to remain stationary when hit by a small (light) object. Prior research with self-propelled objects (e.g., Leslie, 1982, 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.

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.[3] 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 infants habituated to the launching event showed greater recovery of attention than those habituated to the delayed-reaction event, suggesting 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, 1984b; Oakes, 1994). This finding suggested that the infants were not surprised when the second brick did not move off <u>immediately</u> when hit. As such, this finding gave rise to the possibility that infants also might not be surprised if a self-propelled object did not move off <u>at all</u> when hit. Experiment 11 examined this possibility: it asked whether 6-month-old infants would be surprised when 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 received familiarization trials identical to those in Experiment 3 (see Fig. 10): a box emerged from behind a large screen, traveled to the right, and then reversed direction either spontaneously (self-propelled condition) or after hitting a wall partition at the right end of the apparatus (inert condition). Next, all of the infants saw the same test event, on two successive trials: an experimenter's gloved hand hit the box, which remained stationary.

In line with the research summarized above, we predicted that the infants in the inert condition would expect the box to move when hit and would be surprised that it did not; in contrast, the infants in the self-propelled condition would <u>not</u> be surprised that the box did not move when hit, because they could infer that the box was using its internal energy to counteract the hand's impact. We thus predicted that the infants in the inert condition would look reliably longer during the test trials than would the infants in the self-propelled condition.

Results indicated that, although the infants in both conditions looked equally during the familiarization trials, the infants in the inert condition looked reliably longer than those in the self-propelled condition during the test trials. Similar results were obtained in another experiment in which the gloved hand pulled on a strap attached to the left side of the box; as in Experiment 11, the box remained stationary when acted upon.

Together, these results suggest that, by 6 months of age, infants assume that a self-propelled object can use its internal energy to resist or counteract efforts to move it. As such, these results are consistent with the evidence reviewed above that infants are not surprised when a self-propelled object does not move immediately upon being hit (e.g., Leslie, 1982, 1984b; Leslie & Keeble, 1987; Oakes, 1994). When a self-propelled object is hit, infants apparently assume that (1) it can elect to go along with the efforts to move with it (recall that the infants tested by Leslie and Keeble (1987) assumed that the first brick caused the second one to move; and the infants tested by Woodward et al. (1993) may also have assumed that the first human caused the other human to move in the contact test event); or (2) it can elect to resist these efforts, in which case it may choose to move after a delay, or not at all.

5. Can a self-propelled object remain stable in midair?

If young infants believe that a self-propelled object can use its internal energy to resist moving when hit, do they also believe that it can it also use its internal energy to resist falling when released in midair? Experiment 12 (Luo et al., in press) was designed to examine this question.

The point of departure for this experiment came from investigations of infants' responses to support events. We have suggested (Li, Yuan, Needham, & Baillargeon, 2008b; Yuan & Baillargeon, 2008a, 2008b) that infants are born with the intuitive understanding that each object has a weight, which causes it to fall; furthermore, the heavier the object, the greater its tendency to fall. As infants learn about support, they learn about the ways and means by which an object's tendency to fall can be checked: either (1) by the application of a force (as when a person's hand holds an object; the heavier the object, the greater the force needed to hold it in place), or (2) by the introduction of a surface in the path of the object, blocking its fall.

Consistent with this analysis, prior research with inert objects (e.g., Baillargeon, 1995; Baillargeon, Needham, & DeVos, 1992; Hespos & Baillargeon, 2008; Li, Baillargeon, & Needham, 2006, 2008a; Li et al., 2008b; Needham & Baillargeon, 1993; Yuan & Baillargeon, 2008a, 2008b) suggests that, by 2.5 to 3.5 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; 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 to 5.5 months of age, infants identify a first support variable, type-of-contact: 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 only if half or more of the supported object's bottom surface rests on the supporting object.

In contrast to these findings, prior research with self-propelled objects (e.g., Leslie, 1984a) suggests that young infants may not 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. 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 television 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 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; S. P. Johnson, 2004; S. P. Johnson et al., 2003; Kellman & Spelke, 1983; Kochukhova & Gredebäck, 2007; Slater et al., 1996; Spelke et al., 1995a; see also Experiments 4 and 5 above). Had the infants in these experiments been surprised or confused 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 believe that self-propelled objects require no external support to move in midair. Experiment 12 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.

The infants were assigned to an inert or a self-propelled condition and were given the same familiarization trials as in Experiment 11. Next, all of the infants saw the same test event, on two successive trials: to start, an experimenter's gloved hand held the box in midair; after a pause, the hand released the box, which remained stationary (see Fig. 11).

In line with the research summarized above, we predicted that the infants in the inert condition would expect the box to fall when released and would be surprised that it did not; in contrast, the infants in the self-propelled condition would not be surprised that the box did not fall, because they could infer that the box was using its internal energy to counteract its own weight and thus in effect to resist falling. We thus predicted that the infants in the inert condition would look reliably longer during the test trials than would the infants in the self-propelled condition.

Results indicated that, although the infants in the two conditions looked equally during the familiarization trials, the infants in the inert condition looked reliably longer than those in the self-propelled condition during the test trials. Similar results were obtained in another experiment in which the box, instead of being released in midair, was released with only 1/6 or 1/3 of its bottom surface supported on a platform; as before, the box remained stationary when released. The infants in the inert condition realized that the box was released without adequate support and should fall (recall that infants this age have already identified proportion-of-contact as a support variable); in contrast, the infants in the self-propelled condition recognized that the box could remain stable because it could use its internal energy to keep itself in place.

Tests with younger infants

We have suggested that infants are born with an intuitive understanding that each object has a weight which causes it to fall unless this weight is counteracted (1) by a force, which may be either external to the object (e.g., a hand holding a cup) or internal to the object (e.g., a hummingbird hovering near a flower), or (2) by a surface blocking the object's path. If infants are born with this causal knowledge, they should be able to demonstrate it at a very early age. Experiment 13 (Yuan & Baillargeon, 2008a) examined this question, with infants aged 2.5 to 3 months.

The infants were assigned to an inert or a self-propelled condition (see Fig. 12) and saw a supported and an unsupported test event. In the supported event shown in the inert condition, an experimenter's gloved hand held a red cylinder in midair, lowered it onto a platform, released it for a few seconds, and then lifted it back to its starting position. In the unsupported event, the hand performed the same actions but the platform now stood to the side so that the cylinder was released and remained stable in midair. The infants in the self-propelled condition saw similar test events except that the hand was absent and the cylinder moved by itself.

As predicted, the infants in the inert condition looked reliably longer at the unsupported than at the supported event (this result was replicated in another experiment conducted with a slightly different procedure); in contrast, the infants in the self-propelled condition looked about equally at the two test events. These results suggested that, by 2.5 to 3 months of age, infants already hold different expectations about the support of novel inert and self-propelled objects.

However, an alternative interpretation of the results of the self-propelled condition was that the infants were merely confused by the self-propelled cylinder and held no expectation about its behavior. Experiment 14 (Yuan & Baillargeon, 2008a) was designed to address this alternative interpretation and also to confirm the results of the self-propelled condition in Experiment 13 (see Fig. 13). The infants first received a familiarization trial. To start, the infants faced a small table with a scalloped front edge that hid its top surface. An experimenter's gloved hands grasped the two right legs of the table and rotated it forward so that the infants could inspect its top surface. For half the infants, this surface was closed (closed condition); for the other infants, the surface had a large opening in its center (open condition). Next, all of the infants saw the same test event, on two successive trials. At the start of the event, the table stood upright, and a self-propelled cylinder stood stationary in midair above it. The cylinder then moved down, passing through the table until it was visible beneath it, and then returned to its starting position.

Although the infants in the two conditions tended to look equally during the familiarization trial, the infants in the closed condition looked reliably longer during the test trials than did the infants in the open condition. These results suggested two conclusions. First, consistent with the solidity principle discussed in Experiment 2, the infants realized that the self-propelled cylinder could not pass through the closed table; this result in turn suggested that the infants were not, in fact, confused by the cylinder and unable to reason about its displacements. Second, consistent with the results of Experiment 13, the infants were not surprised to see the cylinder travel up and down through the open table, presumably because they inferred that the cylinder was using its internal energy to initiate its motion and counteract its weight so as to resist falling.

Kinds of explanations

To adults, the results of Experiments 12-14 (see also Experiments 4-5) may appear particularly surprising: why would infants believe that a novel self-propelled object can move through the air or can remain stable in midair? However, a moment's reflection is sufficient to realize that from this perspective we are not so very different from infants. If we were watching an unfamiliar insect crawl on a table and saw it suddenly fly to a plant and hover near it, we would not be astounded: if the insect flies and hovers, then it follows that it can fly and hover, and we would take these actions to be part of its behavioral repertoire.

Of course, as adults we know a great deal more than infants do about what physical structures and processes might allow an insect—or any other self-propelled object, such a bird, butterfly, helicopter, or plane—to move through the air. Infants' reasoning in our experiments is no doubt highly abstract and divorced of most mechanistic details: although infants may believe that a self-propelled object can use its internal energy to move through the air, they can have no conception at all of the particular mechanism that allows it to do so.

This notion is strongly reminiscent of Keil's (1995) claim 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 claim, we would argue that the infants in our experiments are offering kinds of explanations, rather than specific or particular explanations, for the actions of our self-propelled objects.

6. Can a self-propelled object act on an inert object?

Do young infants believe that a novel self-propelled object can use its internal energy to control not only its own motion, but also that of other objects? In particular, do they believe that a novel self-propelled object can set an inert object into motion, or prevent it from falling, through the application of force? We discuss each question in turn.

Setting an inert object into motion

If infants believe that (1) an inert object cannot initiate its own motion, and (2) a self-propelled object can use its internal energy to exert a force on an inert object and set it in motion, then the following prediction should hold: if infants see an inert object emerge from behind an occluder and are asked which of two stationary targets, one inert and one self-propelled, could have set it in motion, they should select the self-propelled target. Of course, infants realize that an inert object, once in motion, can cause another inert object to move (e.g., Kotovsky & Baillargeon, 1998, 2000; Wang et al., 2003; Woodward et al., 1993). However, when confronted with two stationary targets, as in the situation described above, infants should correctly infer that only the self-propelled target could have initiated its own motion out of view and acted on the inert object to set it in motion.

A number of researchers have recently examined infants' ability to draw inferences about the likely cause of an inert object's motion (e.g., Kosugi et al., 2003; Saxe et al., 2005, 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 of 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 (1) categorized the hand as a self-propelled object (they no doubt recognized it as a human body part) and the beanbag and block as inert objects (they had no evidence to the contrary); (2) understood that the beanbag could not initiate its own motion; and (3) realized that the hand could have set the beanbag into motion, but the block could not.

The research reported in this chapter suggests that infants should look equally at the different- and same-side events if they saw the block move by itself prior to the test trials so that they 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 (it was controlled by invisible threads). 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 to land on the apparatus floor. 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. This conclusion is consistent with our claim in the last section that infants are producing abstract kinds of explanations, divorced of all mechanistic details, for the actions of self-propelled objects (Keil, 1995).

<u>Preventing an inert object from falling</u>

We saw earlier that infants expect an inert object to fall unless a surface blocks its path or an external force counteracts its weight (e.g., Baillargeon, 1995; Li et al., 2008b; Needham & Baillargeon, 1993; Yuan & Baillargeon, 2008a). This research gave rise to the following question: would infants believe that a novel self-propelled object could use its internal energy to exert a force on an inert object and prevent it from falling (e.g., in the same manner that a hand might hold a cup in midair)? To address this question, we conducted experiments with 4.5- to 5.5-month-old infants (Li et al., 2008a).

Our research built on prior experiments that tested whether 4.5-month-old infants have identified the variable type-of-contact in support events and thus realize that an object can be stable when released on top of, but not against, another object (Li et al., 2006). In a baseline condition, infants were shown a supported and an unsupported test event (see Fig. 14). At the start of each event, a large yellow platform stood on the apparatus floor, and a yellow box rested at the bottom of the platform's right wall. In both test events, an experimenter's gloved hand placed a small green box against the center of the platform's right wall and then released it. In the supported event, the yellow box was sufficiently tall that the green box rested on it; in the unsupported event, the yellow box was much shorter so that the green box rested well above it. The experiment thus asked whether the green box could be stable when resting against the right wall of the platform, with no surface immediately under it. Results indicated that the 4.5-month-old old female infants looked reliably longer at the unsupported than at the supported event, whereas the male infants looked about equally at the two events. Additional results indicated that (1) male infants aged 5 to 5.5 months looked reliably longer at the unsupported than at the supported event, and (2) female infants aged 3.5 to 4 months tended to look equally at the two events. These and control results (in which the hand never released the green box) suggested that the variable type-of-contact is identified a few weeks earlier in female than in male infants, most likely because of female infants' superior depth perception at this stage of development (e.g., Bauer, Shimojo, Gwiazda, & Held, 1986; Gwiazda, Bauer, & Held, 1989a, 1989b). (In order to learn that objects typically fall when released against the side of a platform, infants have to be able to determine whether the objects are released against the platform or in midair next to it; infants would expect the objects to fall when released in midair).

Experiment 15 (Li et al., 2008a) built on the preceding results and asked whether infants would respond differently to the supported and unsupported test events if first shown that the yellow platform was self-propelled (see

Fig. 15). Would infants then conclude that the unsupported event was in fact possible because the platform could use its internal energy to “hold” the green box in place? Participants were 4.5-month-old females and 5.5-month-old males. Prior to seeing the test events, they received two familiarization trials in which they saw the yellow platform move back and forth across the apparatus floor; the small green box stood stationary at the front of the apparatus (to make it clear to the infants that the green box was inert). Unlike the infants in the baseline experiment, those in Experiment 15 tended to look equally at the supported and unsupported events, suggesting that they believed that the self-propelled platform could use its internal energy to “hold” the green box against its midsection.

Of course, another possible interpretation was that the infants were simply confused by the self-propelled platform and thus had no expectation about the outcomes of the subsequent events. To examine this alternative interpretation, in Experiment 16 (Li et al., 2008a; see Fig. 16) 4.5-month-old females and 5.5-month-old males saw the same familiarization and test events as in Experiment 15, with one exception: in the test events, the platform was now shifted 10 cm to the left. The tall and short yellow boxes stood in the same position as before, and the gloved hand performed the same actions as before. Thus, in the supported event the hand placed the green box on the tall yellow box; and in the unsupported event the hand placed the green box in the same position above the short yellow box, so that the green box appeared to float or hover in midair above it. The infants now looked reliably longer at the unsupported than at the supported event, suggesting that (1) they were not confused by the self-propelled platform, and (2) they believed that the self-propelled platform could use its internal energy to “hold” the green box in place when the two were in direct contact, but not when they were separated by a short distance. The infants in Experiment 16 could generate no explanation for why the green box remained stable when released above the short yellow box, and they were thus surprised by this event.

The results of Experiments 15 and 16 are consistent with prior results from collision experiments with inert objects, which suggest that infants as young as 2.5 months of age realize that a force can only be applied through direct contact (e.g., Kotovsky & Baillargeon, in Baillargeon, 1995; Kotovsky & Baillargeon, 2000). These experiments showed that, although infants expect a wheeled toy bug to be displaced when hit by a rolling cylinder, they also expect the bug not to be displaced when a small obstacle prevents the cylinder from coming into direct contact with the bug. In the same manner, the infants in Experiments 15 and 16 apparently understood that the platform could “hold” the green box only through direct contact.

Readers might be puzzled by the results of Experiment 15. How could the infants believe that the yellow platform prevented the green box from falling by exerting a force upon it? The platform could not grip the green box, so how could it “hold” it in place? How could the platform exert a force on the green box directly through its right wall? Here again, following Keil (1995), we believe that infants are generating only an abstract kind of explanation divorced from all specific mechanistic details: they assume that the platform is exerting a force on the green box to “hold” it in place, but they have no idea at all of the mechanism by which this feat is accomplished.

As adults, we too might occasionally find ourselves in the same position as the infants in Experiment 15. Consider the following situation: we are watching a science-fiction movie and see a box-shaped alien creature fly to an inert object on a planet’s surface (e.g., a rock filled with kryptonite), make contact with the object, and fly off with it. We would assume that the alien had used its internal energy to somehow seize and carry off the object—just as the infants in Experiment 15 assumed that the self-propelled platform was using its internal energy to somehow “hold” the green box against its midsection.

7. Summary

The evidence reviewed in this section suggests that, from a very young age, infants distinguish between inert and self-propelled objects. Furthermore, infants seem to endow self-propelled objects with an internal source of energy. On the one hand, infants are not surprised when shown events that can be explained by assuming that a self-propelled object used its internal energy to control its motion or that of other objects. Thus, infants are not surprised when a self-propelled object initiates its own motion; alters the direction of its motion; moves to a different location when out of sight; changes the orientation or position of a part when out of sight; remains stationary when hit or pulled; remains stable when released without adequate external support; and sets an inert object into motion or “holds” it to prevent it from falling. On the other hand, infants are surprised when shown events that cannot be explained by appealing to a self-propelled object’s internal energy. Thus, infants are surprised when a self-propelled object passes through a solid obstacle; magically disappears and reappears out of thin air; changes the location of a part; and perhaps sets an inert object into motion or “holds” it in place without direct contact (infants may construe these last events without reference to the self-propelled object and simply assume that the inert object is behaving in an inexplicable fashion).

II. HOW DO INFANTS CHARACTERIZE SELF-PROPELLED OBJECTS?

In section I, we have provided evidence that infants distinguish between inert and self-propelled objects and attribute to the latter an internal source of energy. But is this really how infants construe self-propelled objects? Perhaps infants view objects that spontaneously initiate or alter their motion as objects that possess a rich constellation of properties, only one of which is self-propulsion. Humans, for example, are not only self-propelled objects: they are also agents that can pursue goals and animals that are composed of biological matter and that can undergo biological transformations such as growth. Is it possible that the infants in our experiments viewed the self-propelled boxes, balls, columns, and cylinders we showed them not merely as self-propelled objects but as agents or animals? We discuss each possibility in turn.

1. Do infants distinguish between self-propelled objects and agents?

When infants see a novel object move by itself across an apparatus, do they tend to view it as an agent that does so because it wants to do so? Recent research (reviewed below) suggests that infants do not in fact equate self-propulsion and agency: a self-propelled object is not necessarily an agent, and an agent is not necessarily self-propelled.

In order to be categorized as an agent, an object must demonstrate that it possesses at least two essential properties: first, its behavior must appear to be autonomous or self-generated; and second, its behavior must appear to be intentional or guided by mental states such as perceptions, dispositions, and goals. For ease of communication, we refer to the first property as autonomy and to the second as intention; each property is discussed in turn.

Autonomy

In a seminar series of experiments, Woodward (1998, 1999) tested 5- to 12-month-old infants' ability to reason about a human agent's motivational states. The infants first received habituation trials in which they faced two toys: object-A, on the left, and object-B, on the right. In each trial, a human agent's left hand reached into the apparatus and grasped object-A. During test, the two toys' positions were reversed, and the agent grasped either object-A (old-object event) or object-B (new-object event). Across experiments, the infants consistently looked longer at the new- than at the old-object event. We take these results to suggest three conclusions: (1) during habituation, the infants attributed to the agent a particular disposition, a preference for object-A over object-B; (2) during test, the infants expected the agent to maintain this preference and hence to form the goal of reaching for object-A in its new position; and hence (3) during test, the infants were surprised when the agent grasped object-B instead of object-A. These results provided the first experimental demonstration that infants as young as 5 months of age can already attribute motivational states—such as dispositions and goals—to agents.

In additional experiments, Woodward (1998) found that infants did not look reliably longer at the new- than at the old-object event when the human agent was replaced with a flat occluder shaped like an arm and hand, a rod tipped with a sponge, or a mechanical claw. Woodward concluded that infants initially attribute goals to human but not to non-human agents. However, there was another possible interpretation for the negative findings of the occluder, rod, and claw experiments: because each object extended from the right side of the apparatus, its right end was hidden from view, making it unclear whether its actions were externally or internally caused. If an object must appear to be acting autonomously to be construed as an agent, then perhaps the infants did not attribute motivational states to the occluder, rod, and claw simply because the available information did not clearly mark them as agents. This interpretation predicted that 5-month-olds might attribute such states to a non-human agent if given unambiguous evidence that they were faced with an autonomous agent.

Experiment 17 (see Fig. 17) examined this prediction (Luo & Baillargeon, 2005a), with 5-month-old infants. The experiment included orientation, familiarization, display, and test trials. During the orientation trials, a small green box moved back and forth across the central portion of the apparatus. During the familiarization trials, a cylinder and cone were placed on either side of the box near the left and right walls of the apparatus, respectively. In each trial, the box moved toward and rested against the cone. During the display trial, the positions of the cone and cylinder were reversed. Finally, during the test trials, the box approached and rested against either the cone (old-object event), as before, or the cylinder (new-object event). As in Woodward's (1998, 1999) experiments, the infants looked reliably longer at the new- than at the old-object event suggesting that (1) they viewed the box as an agent; (2) during familiarization, they attributed to the box a preference for the cone over the cylinder; and (3) during test, they expected the box to maintain this preference and hence to approach the cone in its new position. Support for these conclusions came from a control condition (see Fig. 17) identical to the experimental condition just described, with one exception: during the familiarization trials, only the cone was present. Although the infants in this condition could view the actions of the box during the familiarization trials as directed toward the goal of contacting the cone, they had no information as to whether the box would prefer the cone or the cylinder when both objects were present in test. As a result, the infants tended to look equally at the new- and old-object test events.

The results of Experiment 17 indicated that infants as young as 5 months of age can attribute motivational states to non-human agents. As such, these results provided support for the hypothesis that the infants in Woodward's (1998) experiment failed to attribute motivational states to the occluder, rod, and claw because it was unclear whether these objects were acting autonomously. To provide additional evidence for this interpretation, in Experiment 18 (see Fig. 18) infants were tested with the same procedure as in the experimental condition of Experiment 17, except that a handle was attached to the box (Luo & Baillargeon, 2005a). When the handle was long and protruded from the right side of the apparatus (long-handle condition), making it unclear whether the box was acting autonomously, infants looked about equally at the new- and old-object test events. In contrast, when the handle was short so that the box appeared to be acting on its own (short-handle condition), as in Experiment 17, then infants again looked reliably longer at the new- than at the old-object event.

Together, the results of Experiments 17 and 18 provided evidence for two conclusions. First, infants as young as 5 months of age attribute motivational states not only to human but also to non-human agents. Second, and most relevant to the present discussion, infants do not view an object as an agent if it does not clearly appear to be acting on its own. A rod, claw, or long-handled box that protrudes from one side of an apparatus and consistently approaches object-A over object-B is not seen as an agent exhibiting a preference for object-A because it is unclear whether its behavior is self-generated or is caused by some external force.[4]

Intention

In light of the results of Experiments 17 and 18, should we conclude that the infants in the experiments reviewed in section I of this chapter viewed the self-propelled objects they were shown (e.g., the boxes, balls, columns, cylinders, and so on) as agents? After all, the objects appeared to be acting on their own, with no visible handles guiding them to and fro. However, recent research by Johnson, Csibra, and their colleagues (e.g., Csibra, 2008; Johnson, Shimizu, & Ok, 2007; Shimizu & Johnson, 2004) suggests that autonomous action alone is not sufficient for infants to view a self-propelled object as an agent: the object must also provide evidence that it is acting intentionally; perceptions, dispositions, goals, and/or other mental states inside the object must be causing its actions. In this view, 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 objects whose actions appear to be intentional, or guided by mental states, can be agents. As we will see, infants seem to be sensitive to several types of evidence for intention, from taking turns in a conversation with a partner, to modifying one's behavior in order to achieve a goal, to selecting different means at different times to achieve the same goal. Interestingly, all of these examples involve goal-directed actions, suggesting that intention may be easiest to detect in the context of communicative or other goals, as agents detect and act on or react to external stimuli.

In a seminal series of experiments, Johnson and her collaborators (Johnson et al., 2007; Shimizu & Johnson, 2004) tested 12-month-old infants in a task modeled after that of Woodward (1998). As in Experiments 17 and 18 above, the human agent was replaced with a non-human self-propelled object, an oval-shaped "blob" covered with bright green fiberfill. The blob was placed near the front of the apparatus; at the back of the apparatus were two toys, object-A on the left and object-B on the right. 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 tended to look equally at the new- and old-object events. This negative result suggested that the infants viewed the blob as a self-propelled object—since it initiated its motion in plain sight—but not as an agent: although the blob appeared to move autonomously, it followed the same fixed path on every habituation trial and thus gave no clear evidence that it was acting intentionally.

To borrow an analogy from section I of this chapter, consider an object that emerges from behind a screen and comes to a stop. The object could be self-propelled—but it could also be an inert object set in motion by some external force behind the screen. We saw that in such cases infants typically select the second, weaker interpretation: they do not view an object as self-propelled unless it gives (what they construe as) clear evidence that it possesses an internal source of energy. In the same way, a blob that repeatedly approaches and contacts object-A could be pursuing the goal of approaching its preferred toy—but it could also be a self-propelled object moving on a fixed path that happens to intersect with object-A. The results above suggest that infants again select the second, weaker interpretation: they do not view an object as an agent unless it gives (what they construe as) clear evidence that it possesses mental states.

Support for this interpretation comes from additional results by Johnson and her colleagues (Johnson et al., 2007; Shimizu & Johnson, 2004). 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 obtained in each condition 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 in test, and they thus looked reliably longer when the blob approached object-B instead. 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).

Not surprisingly, positive results were also obtained when the experimenter and the blob conversed at the start of the test session and the blob turned toward object-A at the start of each habituation trial; since each factor alone led to an attribution of agency, both factors together naturally did so as well (Shimizu & Johnson, 2004). Finally, in converging experiments using a "gaze-following" measure, Johnson and her colleagues (e.g., Johnson, 2003; Johnson et al., 1998, 2008) found that, after observing the blob turn toward one of two targets, 14- to 15-month-old infants 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 an object as an agent if its actions appear not only autonomous but also 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 rotates 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, contacting its preferred toy. The same could be said of the self-propelled box in Experiments 17 and 18 (short-handle condition): although the box moved back and forth across the center of the apparatus in the orientation trials, it approached and stopped against the cone 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 to achieve the same goal across trials. This research built on work by Kamewari et al. (2005), which itself was designed to extend earlier work by Csibra, Gergely, and their colleagues (e.g., Csibra et al., 1999; Gergely, Nádasdy, Csibra, & Bíró, 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 either moved in a straight line to the target (new-path event) or followed the same path as before (old-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 novel self-propelled box followed the same fixed path in every habituation trial, infants were not certain whether it was an agent; it was clearly acting autonomously, but there was perhaps insufficient evidence that its actions were intentional. To test this idea, Csibra (2008) again habituated 6.5-month-old infants 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 now positive, suggesting that this slight variation in means was sufficient to lead the infants to conclude that the box's behavior was intentional. They attributed to the box the goal of reaching the target, and they expected it to do so efficiently in every trial. Thus, when the obstacle was removed in test, they expected the box to now move directly toward the target, and they were surprised when it did not.

Together, the results summarized above suggest that for infants a self-propelled object is an agent if it gives evidence that it possesses mental states such as perceptions, dispositions, and goals. To return to the question raised at the start of this section (i.e., did the infants in the experiments reviewed in section I of this chapter view the novel self-propelled objects they were shown as agents?), we suspect that in at least some cases the answer was no. 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.

Inert agents

The research summarized above on autonomy and intention leads to a strong prediction: infants might view an inert object as an agent if it gave evidence that (1) it could produce some behavior on its own and (2) this behavior was guided by mental states. Think, for example, of the Magical Mirror in the fairy tale “Snow White”, who always responds accurately when asked for the name of the fairest woman in the kingdom. Most adults would agree that the Magical Mirror is an inert agent: although it cannot initiate its own motion, its communicative behavior is self-generated and intentional.

Experiments 19 and 20 (Wu & Baillargeon, 2007b) were designed to examine whether 14-month-old infants could view an object as an inert agent. Inspired by the work of Johnson and her colleagues (Johnson et al., 2007, 2008; Shimizu & Johnson, 2004), we used a beeping box as our agent.

In Experiment 19 (see Fig. 19), we first asked whether infants would view a box that responded with beeps in a conversation with an experimenter, but otherwise remained stationary, as inert. Alternative possibilities were that infants might expect any object capable of self-generated behavior (such as beeping) to be self-propelled, or that they might view any agent as self-propelled. To test whether the infants would view the box as inert, we built on the results of Experiments 12-14 and examined whether infants would expect the box to fall when released in midair.

The infants were assigned to an inert or a self-propelled condition. The only difference between the two conditions involved the first, orientation trial: the box either remained stationary (inert condition) or moved back and forth a short distance (self-propelled condition). Next, in a conversation trial, all infants observed an experimenter (with bare hands) participate in a scripted conversation with the box. The experimenter sat at window in the left side of the apparatus and spoke English; the box responded with varying series of beeps. Following the conversation (which lasted about 47 s), the experimenter closed the curtain in the window and the box remained stationary and silent until the trial ended. In the next, familiarization trial, the box was held above the apparatus floor by a gloved hand that reached through a fringed curtain in the window. Finally, in the test trial, the hand released the box, which remained stationary in midair.

Although the infants in the self-propelled condition looked reliably longer than those in the inert condition during the orientation trial (not surprisingly, the box was more interesting when it moved than when it remained stationary), the infants in both conditions tended to look equally during the conversation and familiarization trials. During the test trial, however, the infants in the inert condition looked reliably longer than those in the self-propelled condition. Together, these results suggested that the infants in the inert condition viewed the box as an inert agent: although it beeped in response to the experimenter in the conversation trial, it never moved on its own and hence possessed no internal energy that could allow it to resist falling when released in midair.

Experiment 20 was designed to provide additional support for the notion that the infants in the inert condition viewed the box as an inert agent (see Fig. 20). Like Experiments 17 and 18, and like the experiments of Johnson and her colleagues (Johnson et al., 2007; Shimizu & Johnson, 2004), Experiment 20 was modeled after Woodward's (1998) work and asked whether infants would attribute to a box that beeped only when one of two toys was revealed a preference for that toy over the other toy. The infants first received the same orientation and conversation trials as in the inert condition of Experiment 19. Next, the infants received familiarization trials in which the box stood centered and behind two small covers. Hidden under the covers were two toys, a ball and a block; toy position (left or right cover) was counterbalanced across infants. A gloved hand lifted and lowered the left cover and then the right cover; the box beeped when the left cover was lifted to reveal object-A, but not when the right cover was lifted to reveal object-B. Next, the infants received a display trial in which the box was absent and the hand lifted and lowered each cover in turn to show that the toys' positions had been reversed. Finally, in the test trials, the box stood in its original position, the hand lifted and lowered the left and right covers in turn, and the box beeped when object-B but not object-A was revealed (new-object event), or when object-A but not object-B was revealed (old-object event). Results indicated that the infants looked reliably longer at the new- than at the old-object event, suggesting that they (1) viewed the box as an agent based on its behavior in the conversation trial, (2) attributed to the box a preference for object-A over object-B during the familiarization trials, and (3) expected this preference to be maintained in the test trials and were therefore surprised in the new-object event when it beeped to object-B instead of object-A. This interpretation was supported by the results of a control condition similar to that in Experiment 17: when only one toy was present in the familiarization trials, the infants tended to look equally at the new- and old-object test events, because they had no information as to which toy the box would prefer when both were present in test.

2. Do infants distinguish between self-propelled objects and animals?

In the previous section, we asked whether the infants in the experiments reviewed in section I of this chapter might have viewed the self-propelled objects they were shown as agents. In this section, we ask whether the infants might have viewed the objects as animals. As might be expected, how one answers this question depends on how one characterizes infants' concept of animal; here we consider two possible characterizations.

Animals as self-propelled agents

In a recent chapter, Mandler (in press) 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 may be clear from the evidence and arguments presented in previous sections of this chapter, our position differs from that of Mandler (in press) on several counts. First, although we also emphasize the central importance of the concepts self-propelled object and agent for infants, we see each of these concepts as embedded in a causal framework—the concept of self-propelled object (with its link to internal energy) in the causal framework that makes possible infants' physical reasoning (e.g., Baillargeon et al., 2006, in press; Gelman et al., 1995; Leslie, 1994; Spelke, 1994), and the concept of agent (with its link to mental states) in the causal framework that makes possible infants' psychological reasoning (e.g., Gergely & Csibra, 2003; Johnson, 2003; Luo & Baillargeon, 2007;

Premack, 1990; Scott & Baillargeon, in press; Song, Onishi, Baillargeon, & Fisher, in press). Second, infants appear to realize that self-propelled objects may not be agents, and that agents may not be self-propelled, suggesting that they recognize that the world of objects is not simply composed of inert objects and self-propelled agents.

Despite these differences, we can still adopt Mandler's (in press) suggestion that for infants animals are essentially self-propelled agents. If this hypothesis is correct, then it is likely that the infants in the experiments reported in section I of this chapter did not view the novel self-propelled objects they were shown as animals: as was discussed earlier, there was typically little or no evidence that the objects were agents.

Animals as self-propelled biological agents

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 an agent: it must also be composed of the "right kind of stuff", namely, "biological stuff" (p. 347). This is because young children's reasoning about animate objects is informed by domain-specific causal principles which allow them to appreciate "the connection between biological matter and animate motion" (p. 346). As the authors point out, "although all objects obey the laws of physics, animate objects also obey biochemical ones...the cause of animate motion and change comes from the channeled release of internally stored chemical energy that is characteristic of biological entities" (p. 346). Although young children do not possess an adult-like biological theory (e.g., their attribution of animate properties to animals is highly selective; see also Carey, 1985), their concept of animal still has fundamental biological properties. Thus, when asked which objects can move by themselves and which cannot, children typically justify their answers with "relevant comments about their material composition and the inside of these objects" (p. 369).

What are the implications of the research and theoretical views of Subrahmanyam et al. (2002) for infants' reasoning about animals? There are at least two developmental possibilities. One is that infants attribute internal energy to self-propelled agents without distinguishing between biological and non-biological energy. In this view, as in Mandler's (in press) view, animals are initially self-propelled agents. In the course of development, children would come to recognize that (1) certain self-propelled agents—animals—are made of "biological stuff", and (2) animals' energy emanates from the very stuff they are made of. Such expectations appear to be in place by at least 4 years of age: for example, Gottfried and S. A. 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 and grow (see also Massey & Gelman, 1988; S. A. Gelman & Gottfried, 1996; Morris, Taplin, & S. A. Gelman, 2000).

Another (perhaps complementary) developmental possibility is that infants possess expectations about self-propelled agents that go beyond their separate properties of being self-propelled and agents and that might be characterized as biological. One such expectation has to do with the notion of insides. Previous research suggests that by 3 to 5 years of age children already expect animals and artifacts to have different insides (e.g., Gelman, 1990; S. A. Gelman & Gottfried, 1996; Gottfried & S. A. Gelman, 2005; Simons & Keil, 1995). Here we are focusing on the simpler question of whether infants expect certain objects to have insides. If infants expect self-propelled agents to have insides (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 reducible to that of self-propelled agent. We are beginning experiments to explore this possibility.

III. CONCLUSIONS

The evidence reviewed in this chapter suggests three broad conclusions. First, from a very early age, infants distinguish between inert and self-propelled objects and endow self-propelled objects with an internal source of energy. A self-propelled object can use its internal energy either directly to control its own motion (e.g., to alter the direction of its motion, to move to a new location, to change the orientation or position of its parts, to resist moving when hit, or to resist falling when released in midair) or indirectly to control the motion of other objects, through the application of force (e.g., to set another object in motion or to prevent it from falling).

Second, just as infants do not view an object as self-propelled unless it provides (what they construe as) unambiguous evidence that it can move itself and thus has internal energy, infants do not view a self-propelled object as an agent unless it provides (what they construe as) unambiguous evidence that it can act intentionally and thus has mental states. Infants thus appear to hold separate concepts of self-propelled object and agent, the first rooted in the causal framework that makes possible their physical reasoning, and the second rooted in the causal framework that makes possible their psychological reasoning. Whether infants possess separate concepts of self-propelled agent and of animal is at present unclear.

Finally, infants' concepts of self-propelled object and agent function as abstract "kinds of explanations" (Keil, 1995; Wilson & Keil, 2000) that are devoid of all mechanistic details but still make possible rich inferences about objects' actions in new contexts. Thus, infants who endow a box that initiates its own motion with internal energy may not understand exactly how this internal energy works or where it comes from, but they recognize that the box can also use its energy to counteract a force exerted by another object (e.g., to remain stationary when hit) or to exert a force of its own (e.g., to hold objects so as to prevent them from falling).

Together, these various lines of evidence are thus helping us to better understand the conceptual basis of infants' cognitive development.

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Footnotes

1. The expectation that an inert object traveling on a horizontal plane will follow 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).

2. 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 is a categorical rather than a proportional measure: it tells us whether infants view an event as unexpected, not how unexpected it appears to them.

3. 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.

4. Recent research suggests that, if provided with sufficient cues, infants may view the actions of a rod or claw that protrudes from one side of an apparatus as goal-directed in the sense that they construe the rod or claw as a mechanical device or tool manipulated by an unseen agent to achieve a certain goal (e.g., Biro & Leslie, 2007; Hofer, Hauf, & Aschersleben, 2005).

Figure Captions

Figure 1: Schematic drawing of the familiarization and test events used in Experiment 1 (Luo et al., in press).

Figure 2: Schematic drawing of the familiarization, orientation, and test events used in Experiment 2 (Luo et al., in press).

Figure 3: Schematic drawing of the familiarization and test events used in the one-screen condition of Experiment 3 (Luo et al., in press).

Figure 4: Schematic drawing of the familiarization and test events used in the two-screen condition of Experiment 3 (Luo et al., in press).

Figure 5: Schematic drawing of the familiarization and test events used in Experiment 4 (Wu et al., 2006).

Figure 6: Schematic drawing of the orientation, familiarization, and test events used in the closed condition of Experiment 5 (Wu et al., 2008).

Figure 7: Schematic drawing of the orientation, familiarization, and test events used in the open condition of Experiment 5 (Wu et al., 2008).

Figure 8: Schematic drawing of the familiarization and test events used in Experiment 6 (Wu & Baillargeon, 2006).

Figure 9: Boxes used to investigate infants' sensitivity to an orientation change (Experiments 6 and 7; Wu & Baillargeon, 2006), a position change (Experiment 8; Wu & Baillargeon, 2008), a location change (Experiment 9; Wu & Baillargeon, 2008), and an appearance change (Experiment 10; Wu & Baillargeon, 2007a).

Figure 10: Schematic drawing of the familiarization and test events used in Experiment 11 (Luo et al., in press).

Figure 11: Schematic drawing of the familiarization and test events used in Experiment 12 (Luo et al., in press).

Figure 12: Schematic drawing of the test events used in Experiment 13 (Yuan & Baillargeon, 2008a).

Figure 13: Schematic drawing of the familiarization and test events used in Experiment 14 (Yuan & Baillargeon,

Figure 14: Schematic drawing of the test events used in the baseline condition of Li et al. (2006).

Figure 15: Schematic drawing of the familiarization and test events used in Experiment 15 (Li et al., 2008a).

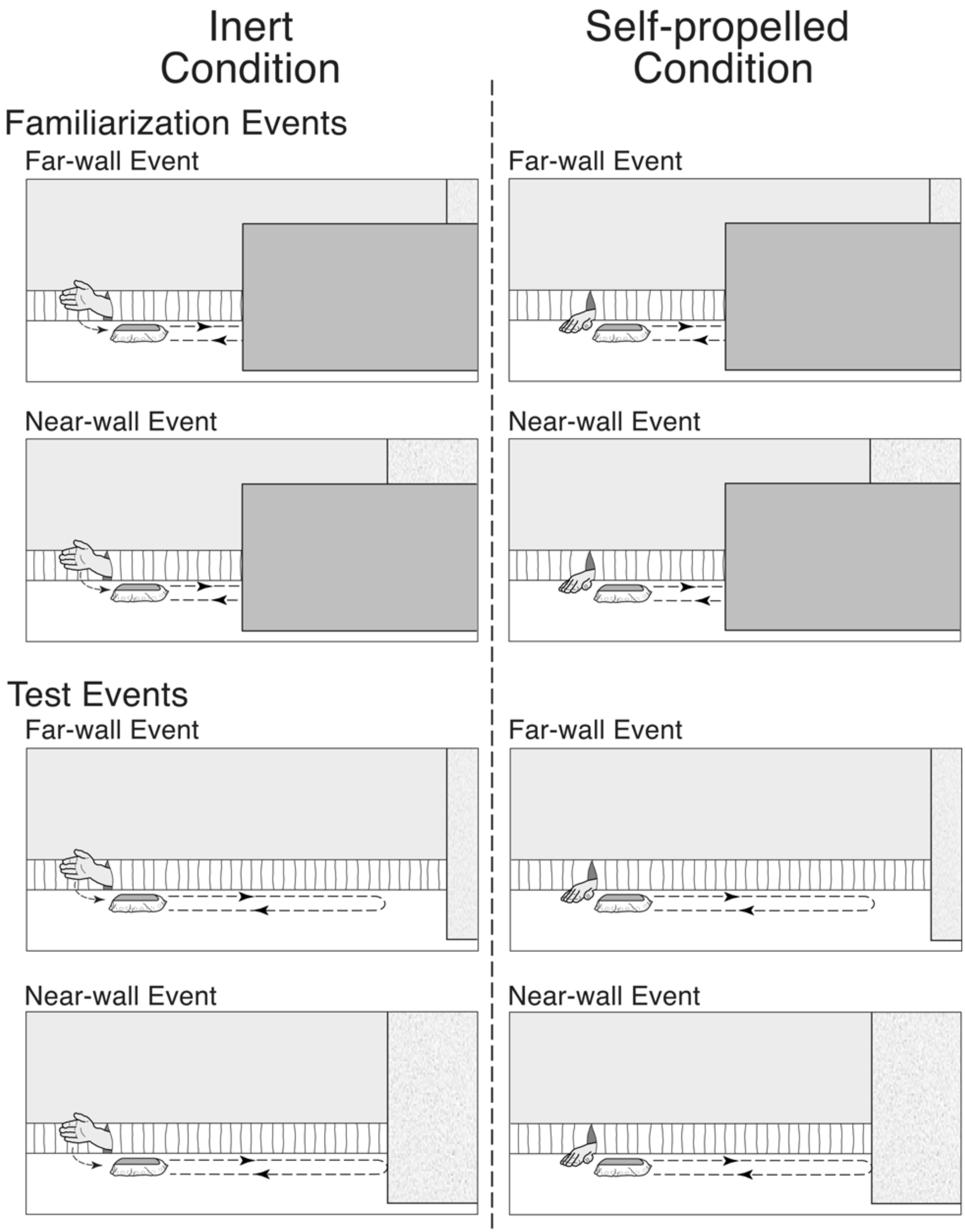
Figure 16: Schematic drawing of the familiarization and test events used in Experiment 16 (Li et al., 2008a).

Figure 17: Schematic drawing of the orientation, familiarization, display, and test events used in Experiment 17 (Luo & Baillargeon, 2005a).

Figure 18: Schematic drawing of the orientation, familiarization, display, and test events used in Experiment 18 (Luo & Baillargeon, 2005a).

Figure 19: Schematic drawing of the orientation, conversation, familiarization, and test events used in Experiment 19 (Wu & Baillargeon, 2007b).

Figure 20: Schematic drawing of the orientation, familiarization, display, and test events used in Experiment 20 (Wu & Baillargeon, 2007b).


Inert
Condition
Self-propelled
Condition
Familiarization Events
Far-wall Event
Far-wall Event
Near-wall Event
Near-wall Event
Test Events
Far-wall Event
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Near-wall Event
Near-wall Event

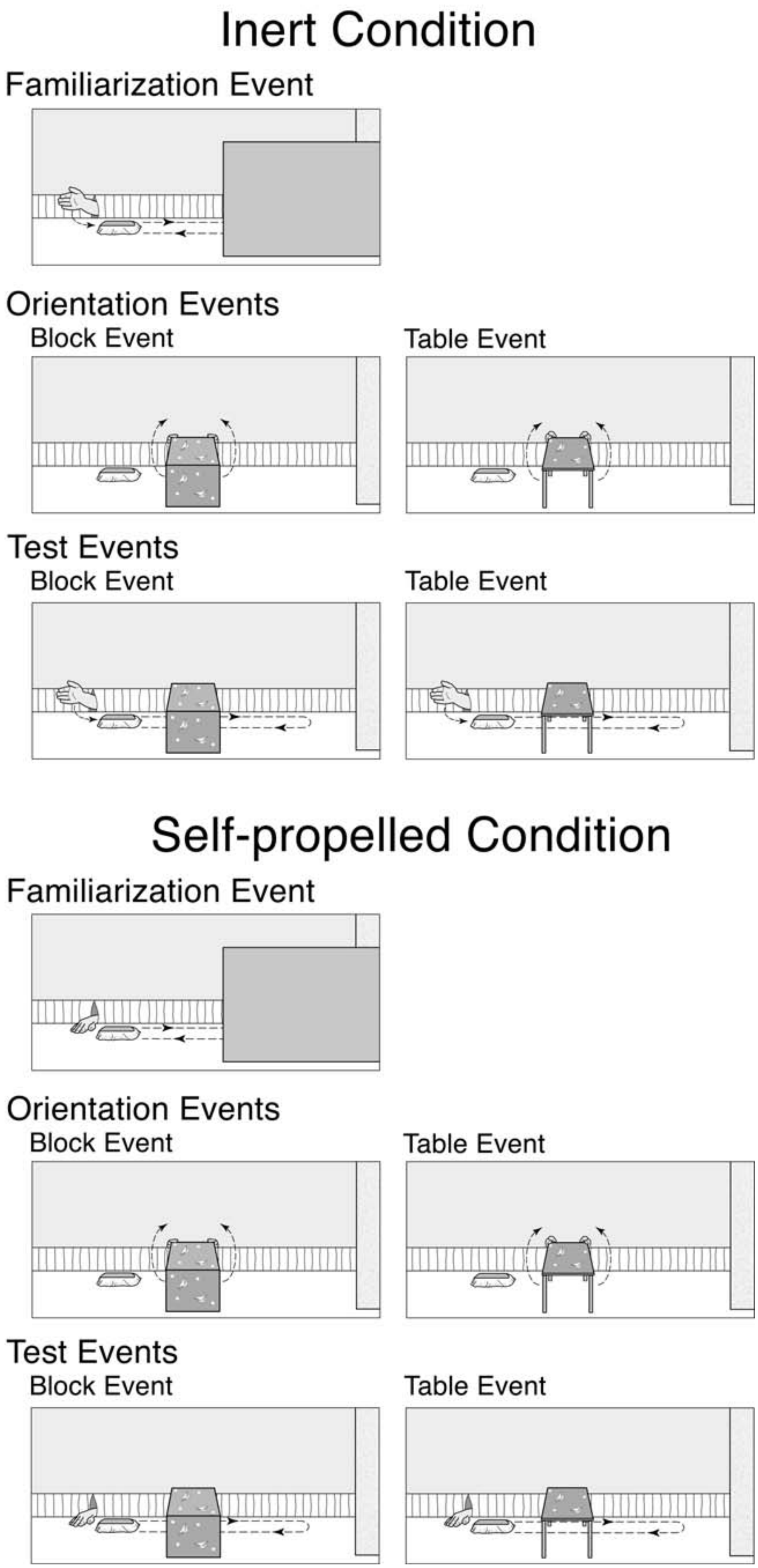
Inert Condition
Familiarization Event
Orientation Events
Block Event
Table Event
Test Events
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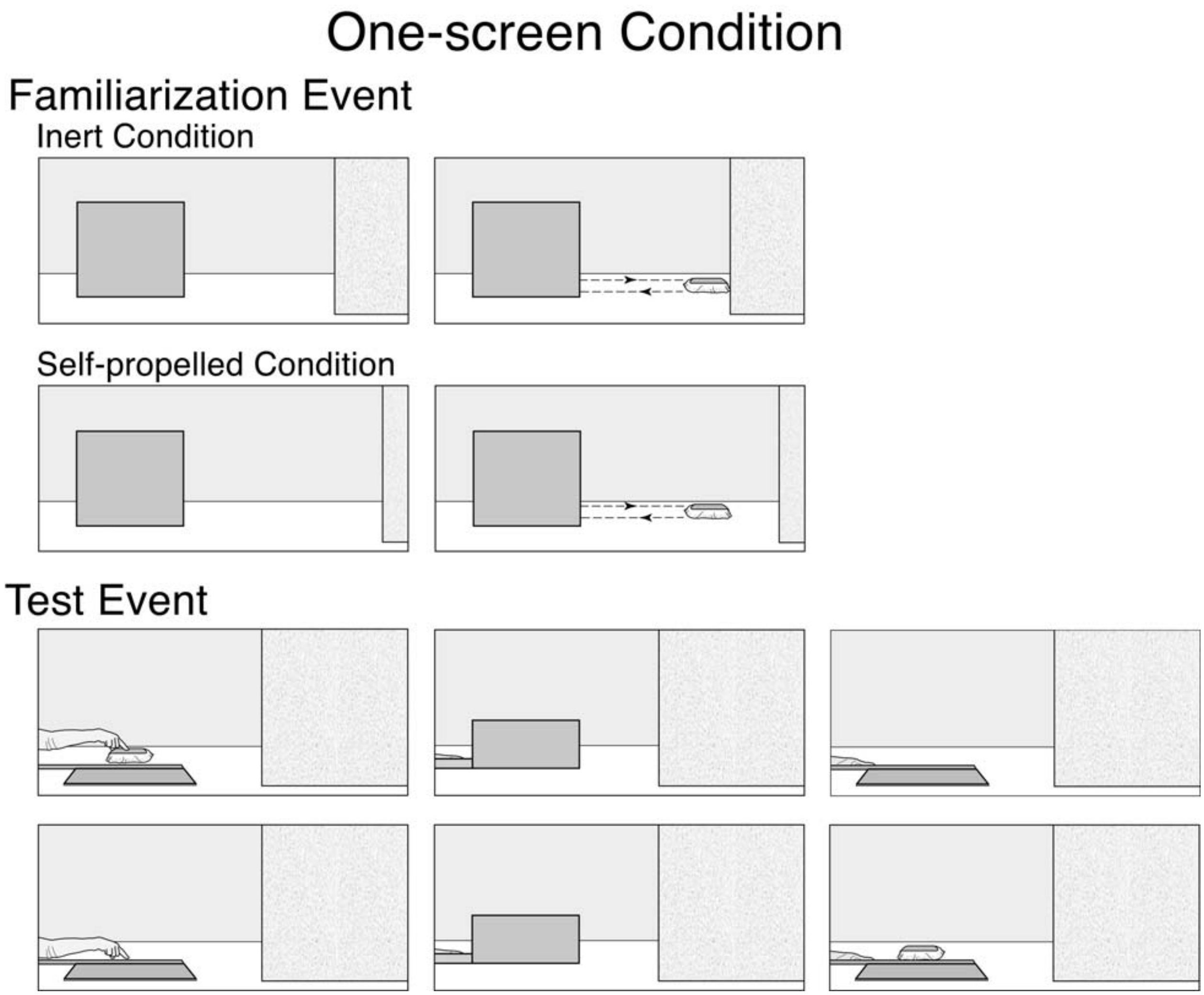
Table Event
Self-propelled Condition
Familiarization Event
Orientation Events
Block Event
Table Event
Test Events
Block Event
Table Event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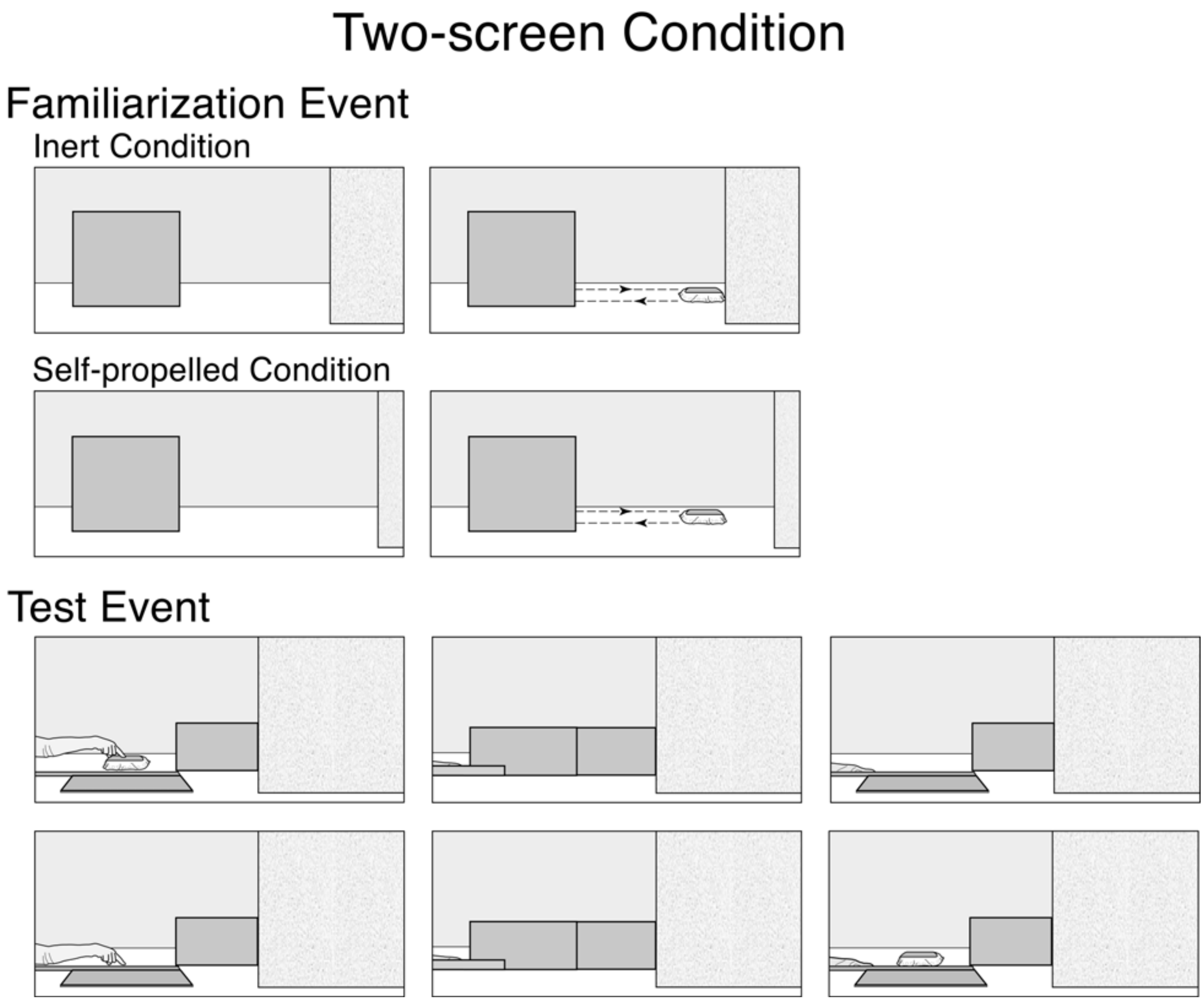
Familiarization Event
Inert Condition
Self-propelled Condition
Test Event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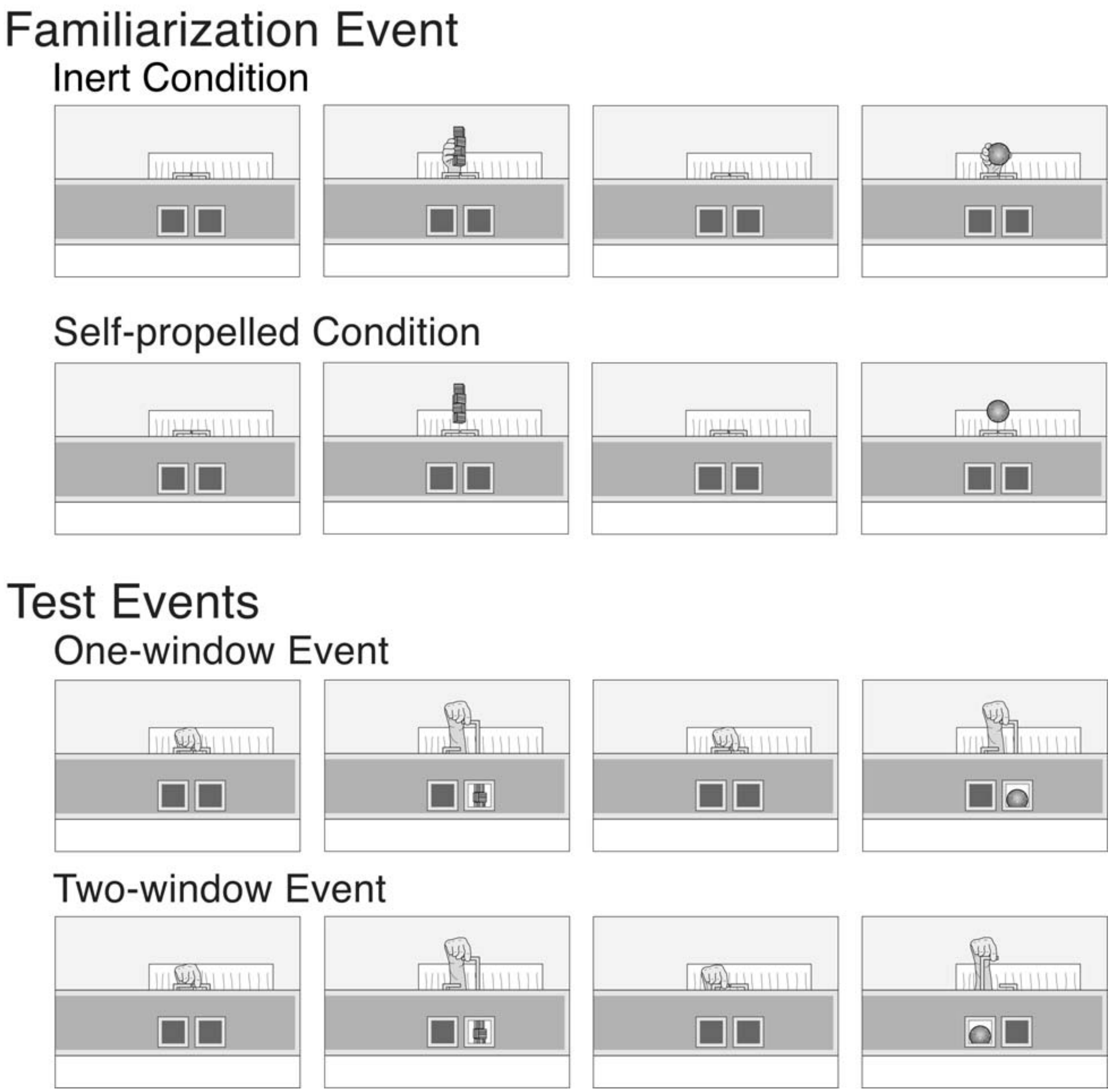
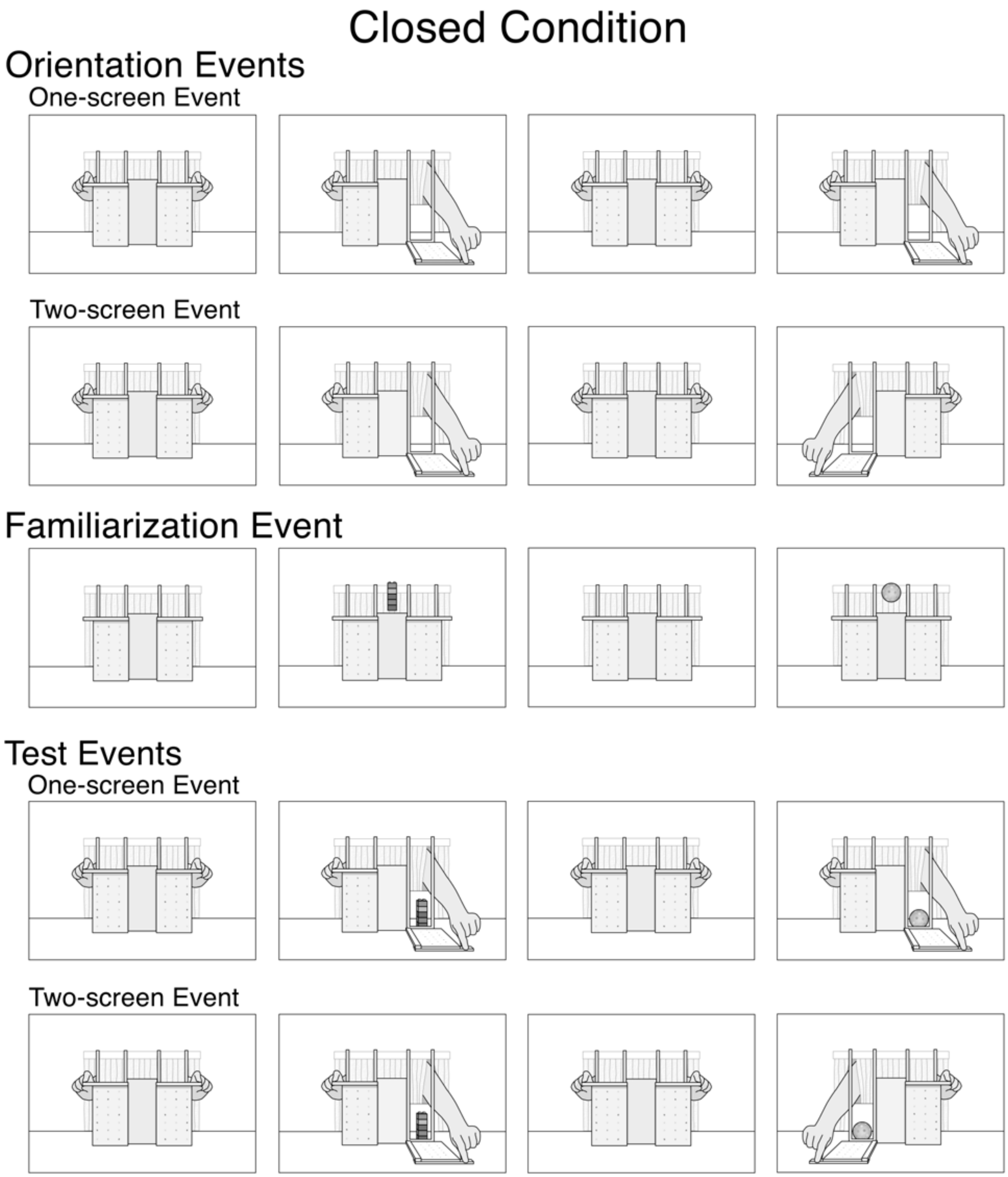
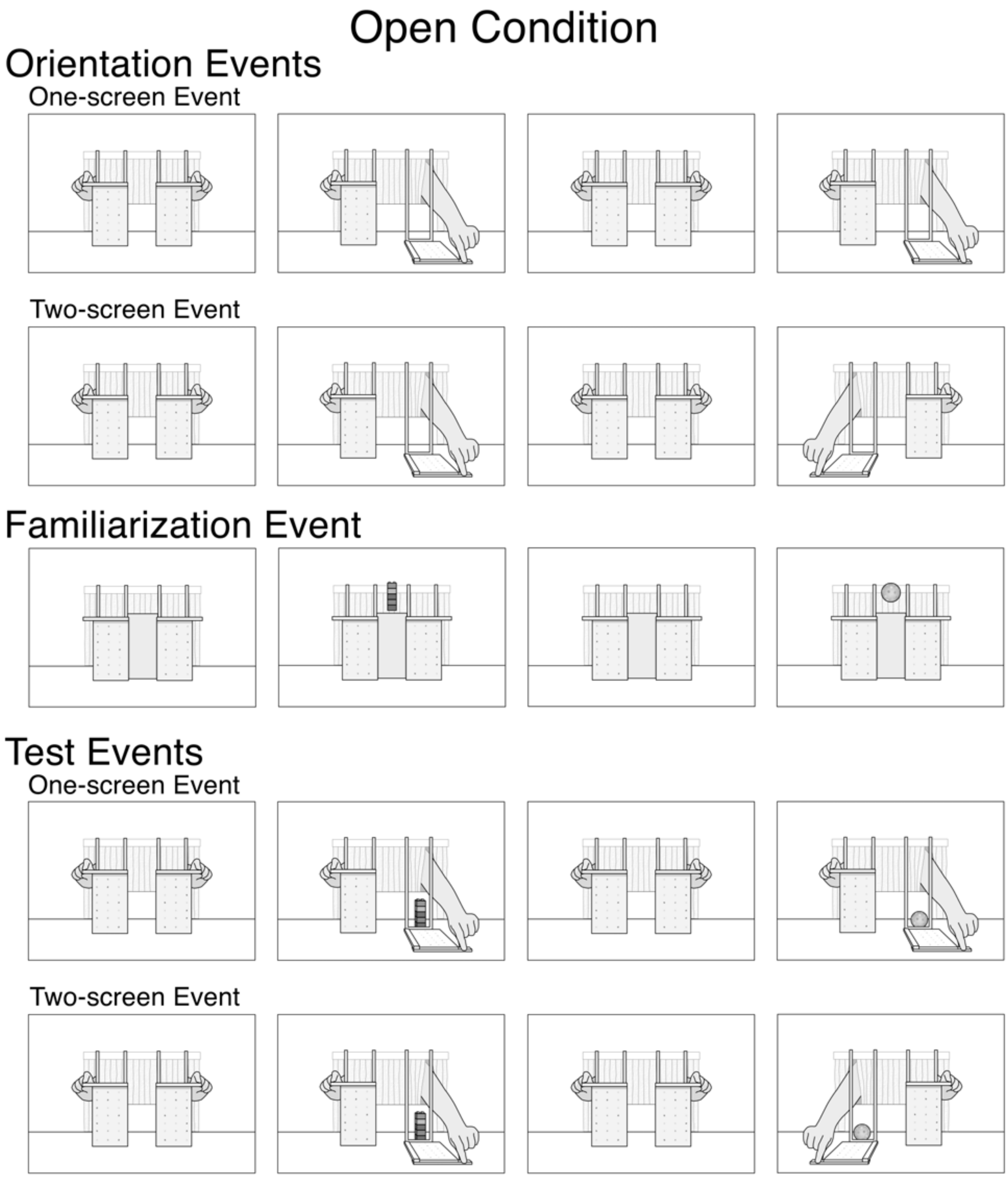
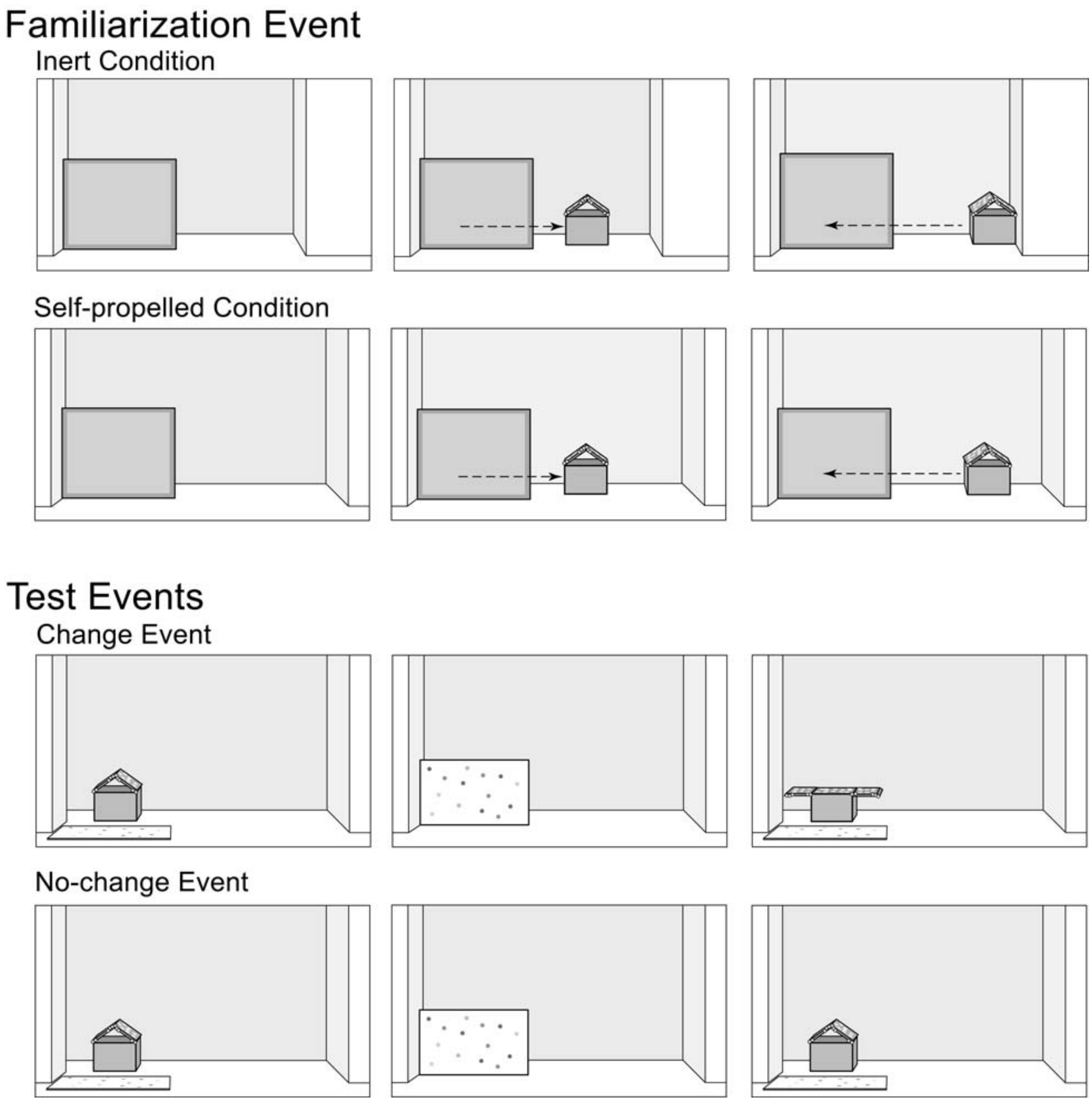
Familiarization Event
Inert Condition
Self-propelled Condition
Test Event


Familiarization Event
Inert Condition
Self-propelled Condition
Test Events
One-window Event
Two-window Event


Closed Condition
Orientation Events
One-screen Event
Two-screen Event
Familiarization Event
Test Events
One-screen Event
Two-screen Event


Open Condition
Orientation Events
One-screen Event
Two-screen Event
Familiarization Event
Test Events
One-screen Event
Two-screen Event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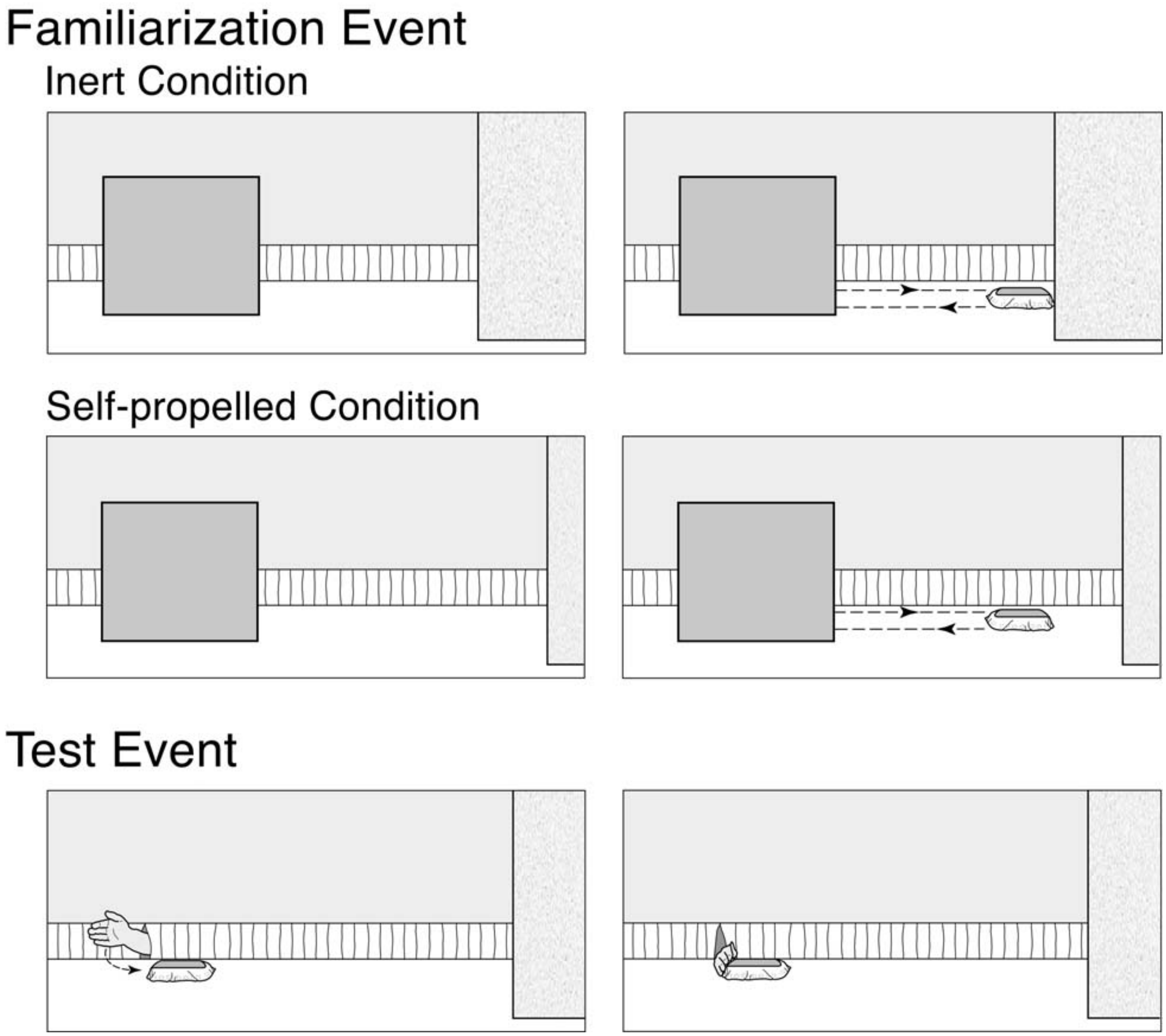
Inert Condition
Self-propelled Condition
Test Events
Change Event
No-change Event

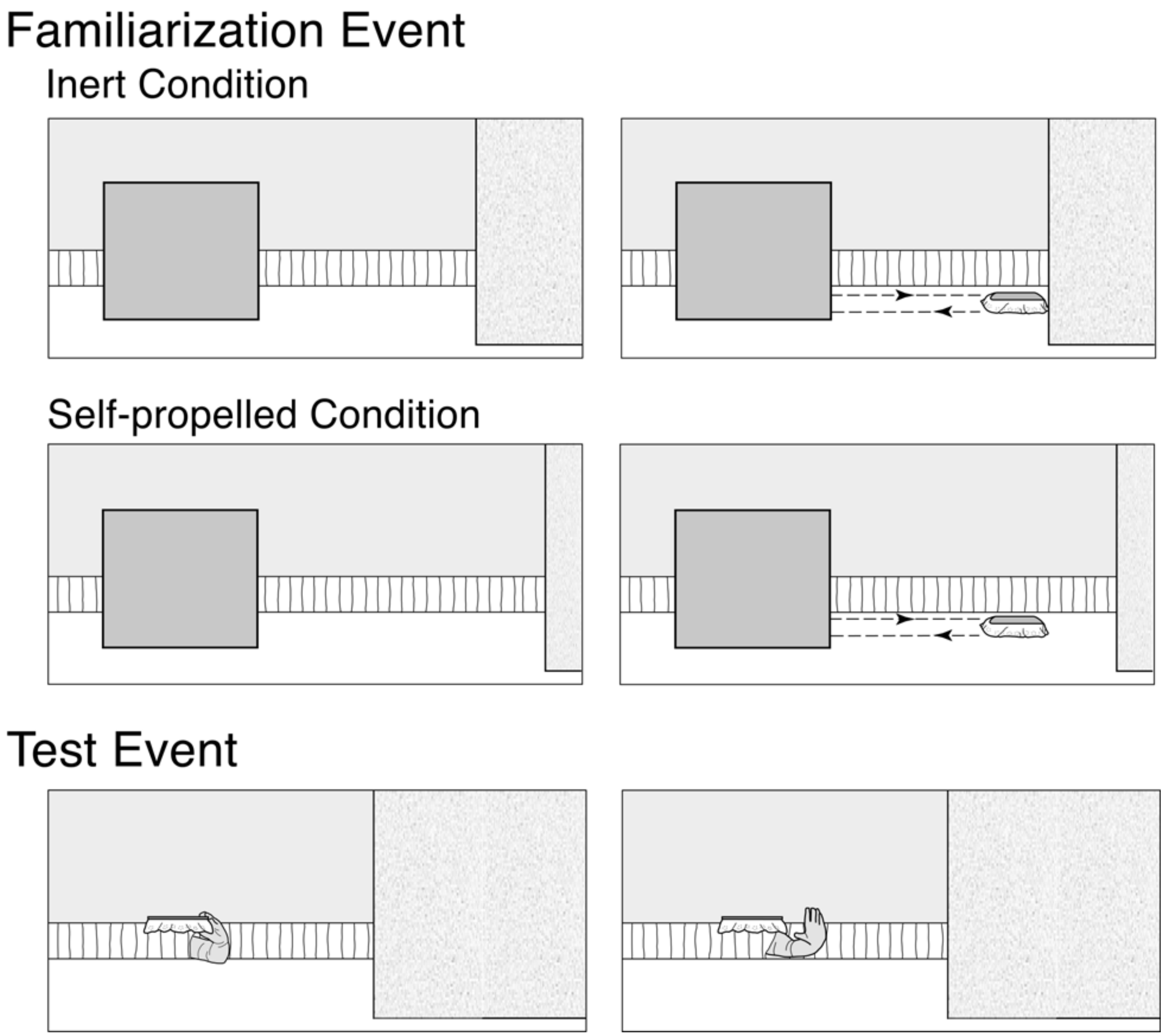
Orientation Change

Position Change

Location Change

Appearance Change


Familiarization Event
Inert Condition
Self-propelled Condition
Test Event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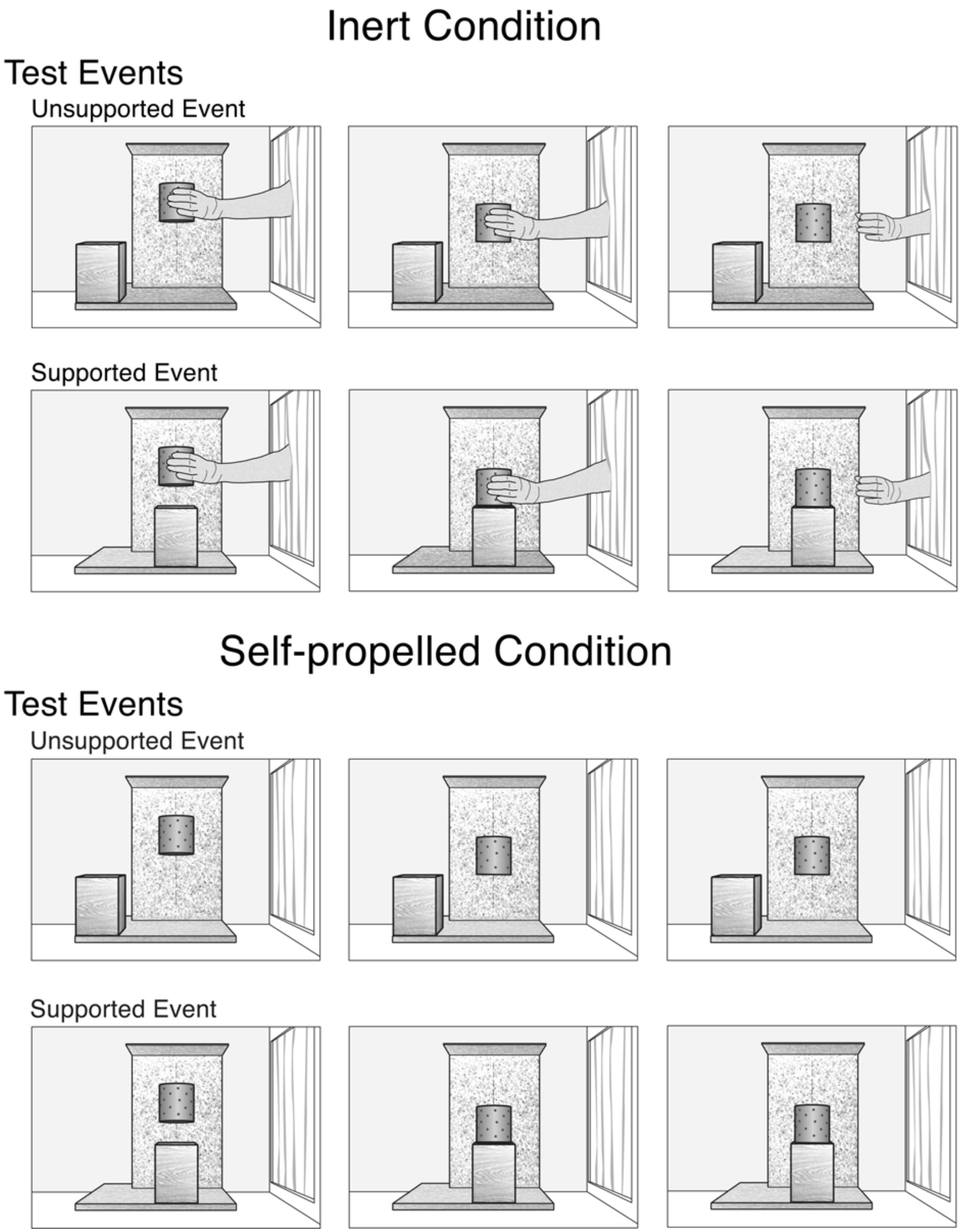
Inert Condition
Self-propelled Condition
Test Event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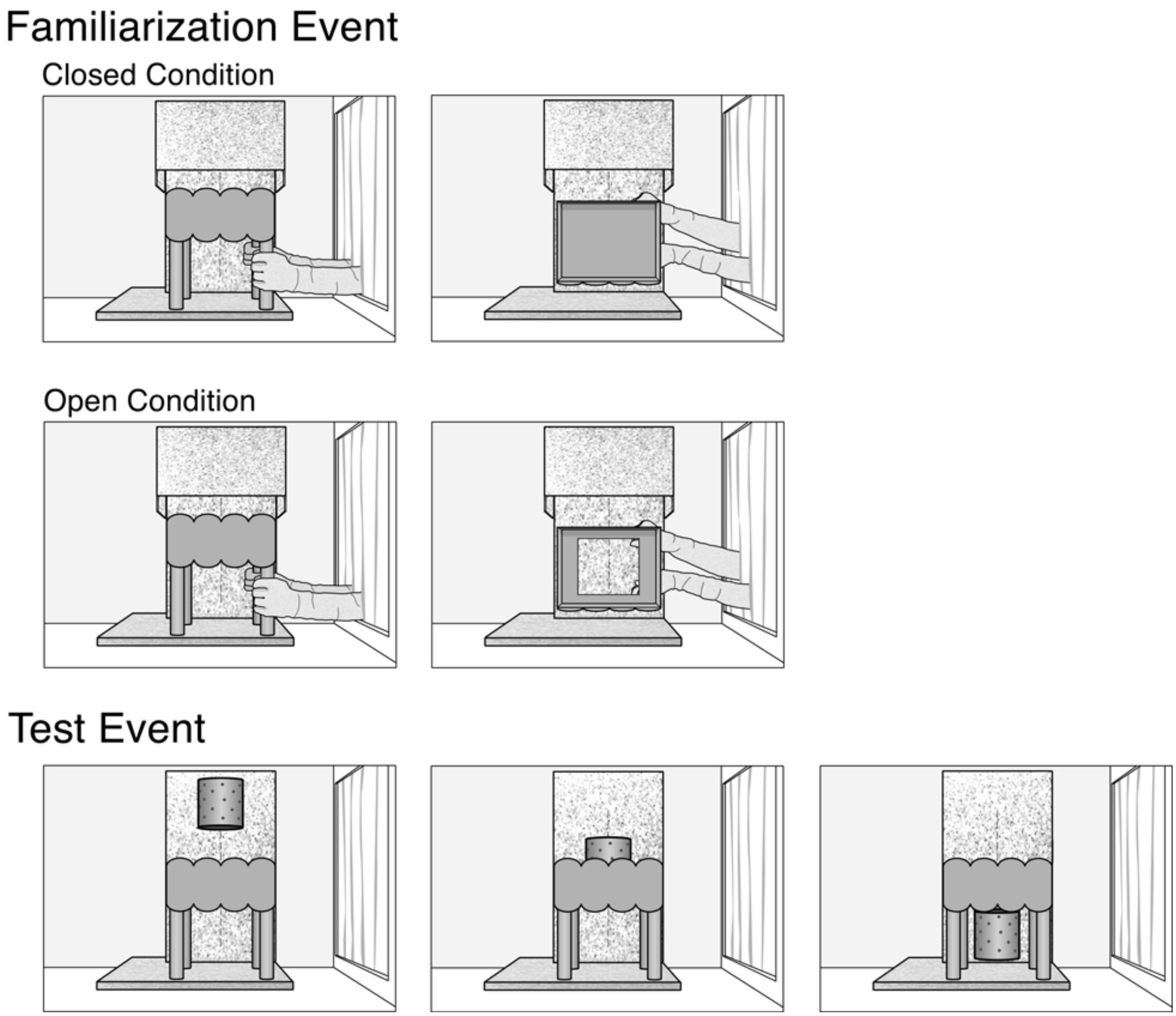
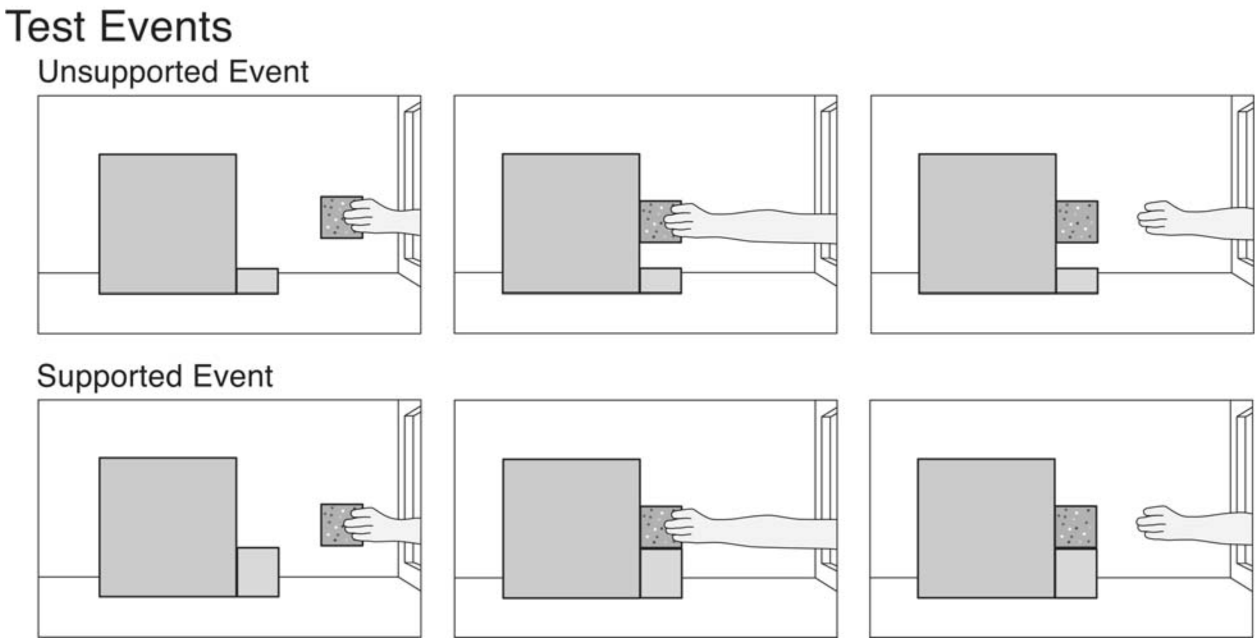
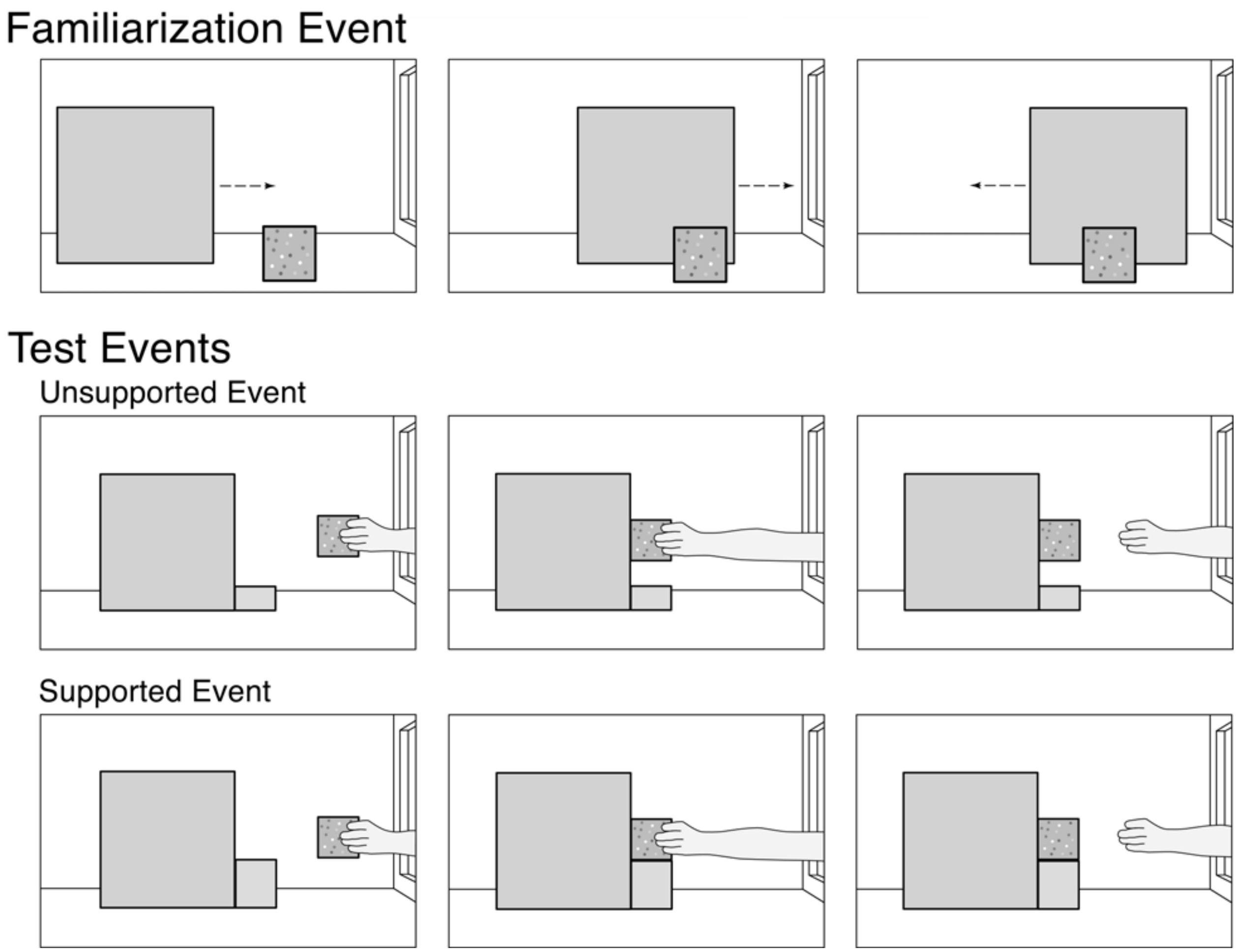
Test Events
Unsupported Event
Supported Event
Self-propelled Condition
Test Events
Unsupported Event
Supported Event


Familiarization Event
Closed Condition
Open Condition
Test Event

Baseline Condition

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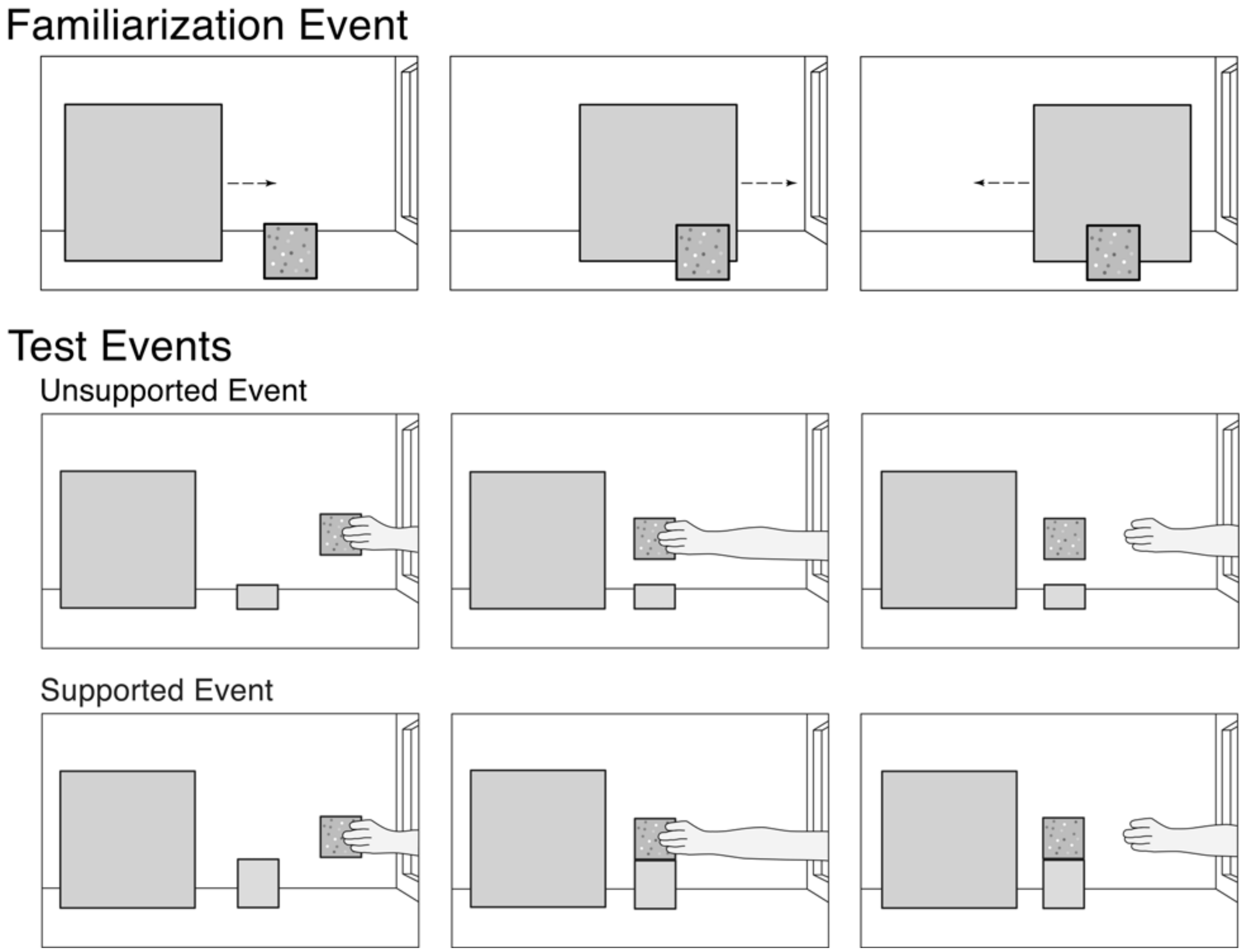
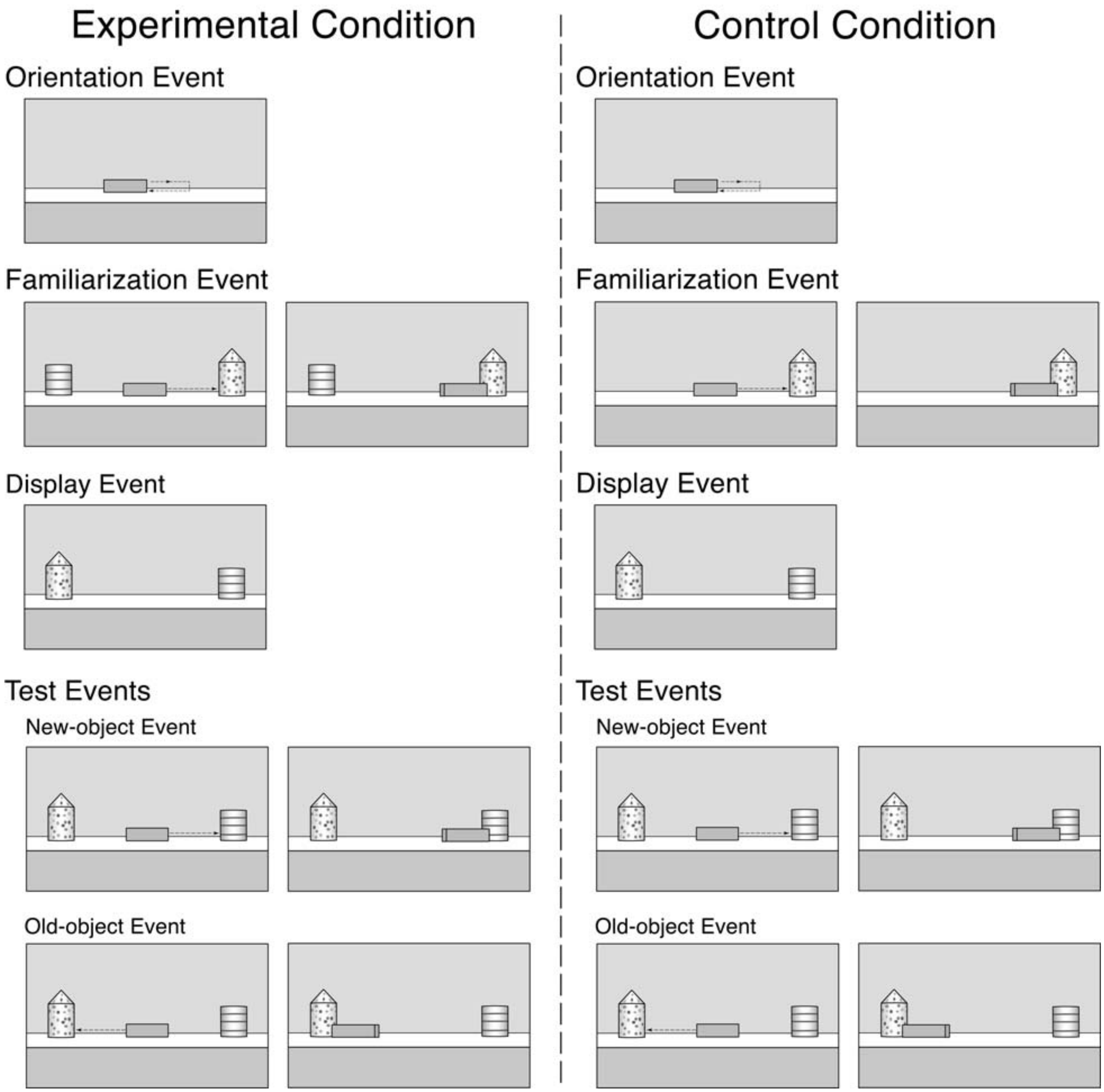
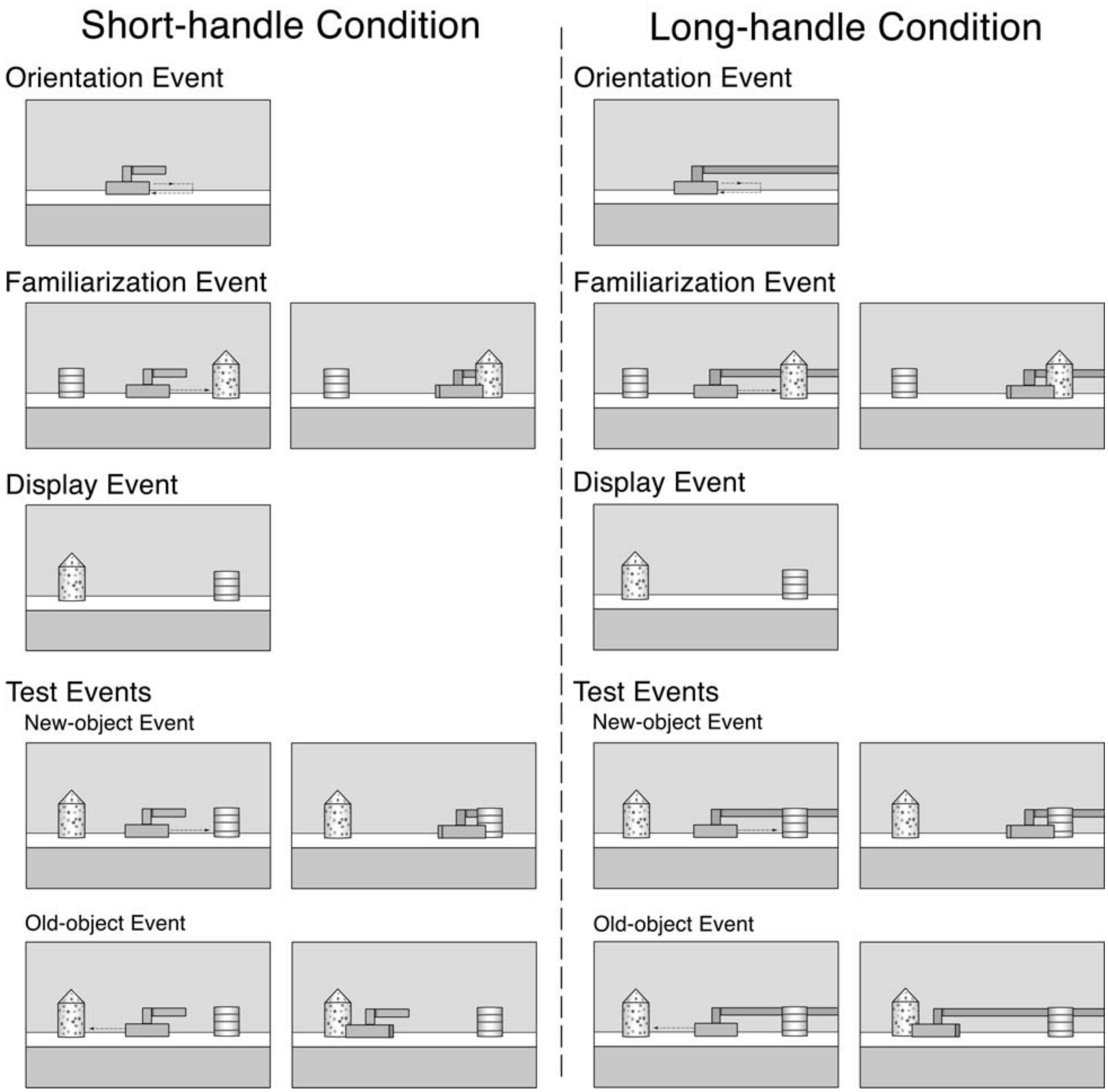
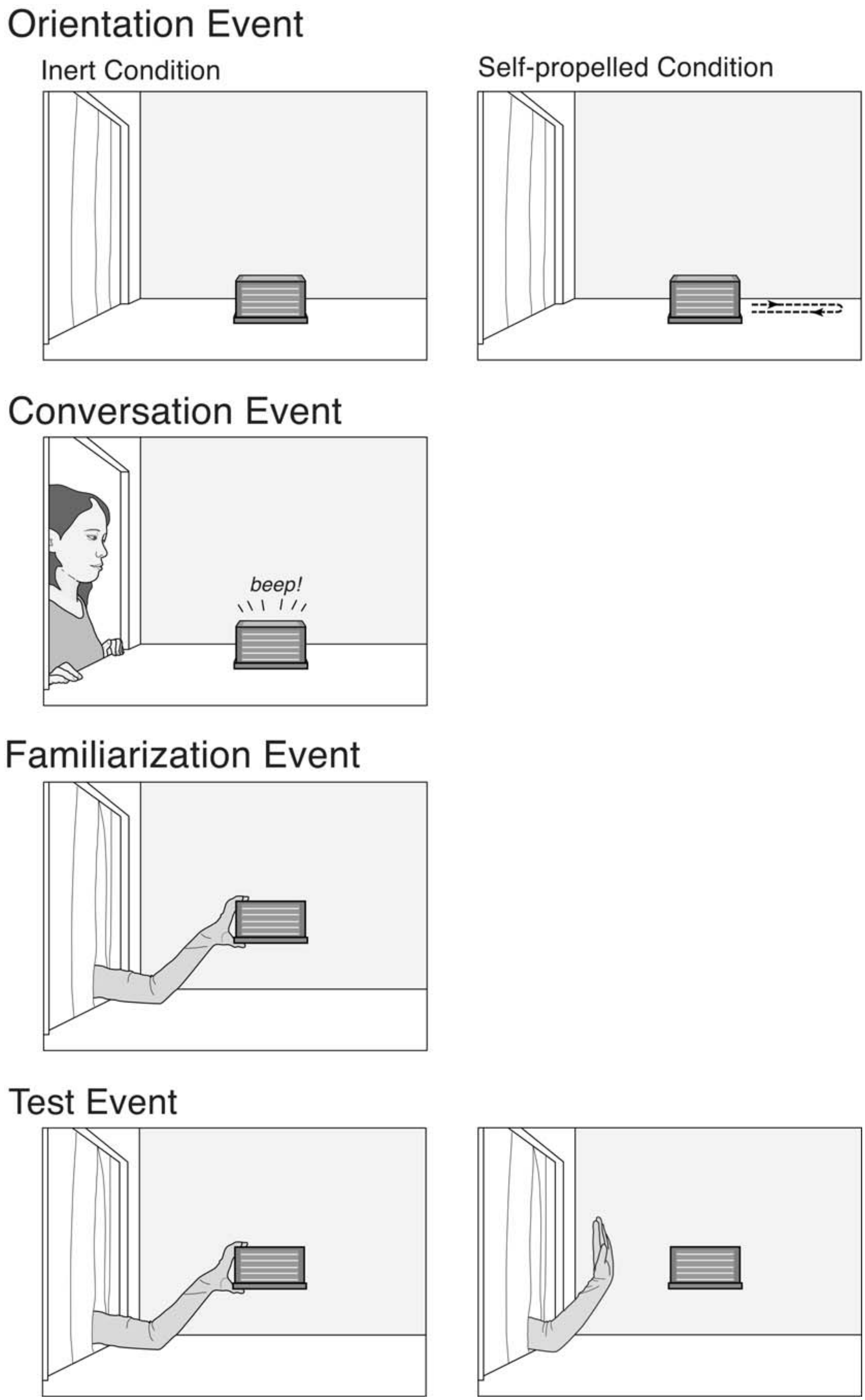
Test Events
Unsupported Event
Supported Event


Familiarization Event
Test Events
Unsupported Event
Supported Event


Experimental Condition
Orientation Event
Familiarization Event
Display Event
Test Events
New-object Event
Old-object Event
Control Condition
Orientation Event
Familiarization Event
Display Event
Test Events
New-object Event
Old-object Event



Short-handle Condition
Orientation Event
Familiarization Event
Display Event
Test Events
New-object Event
Old-object Event
Long-handle Condition
Orientation Event
Familiarization Event
Display Event
Test Events
New-object Event
Old-object Event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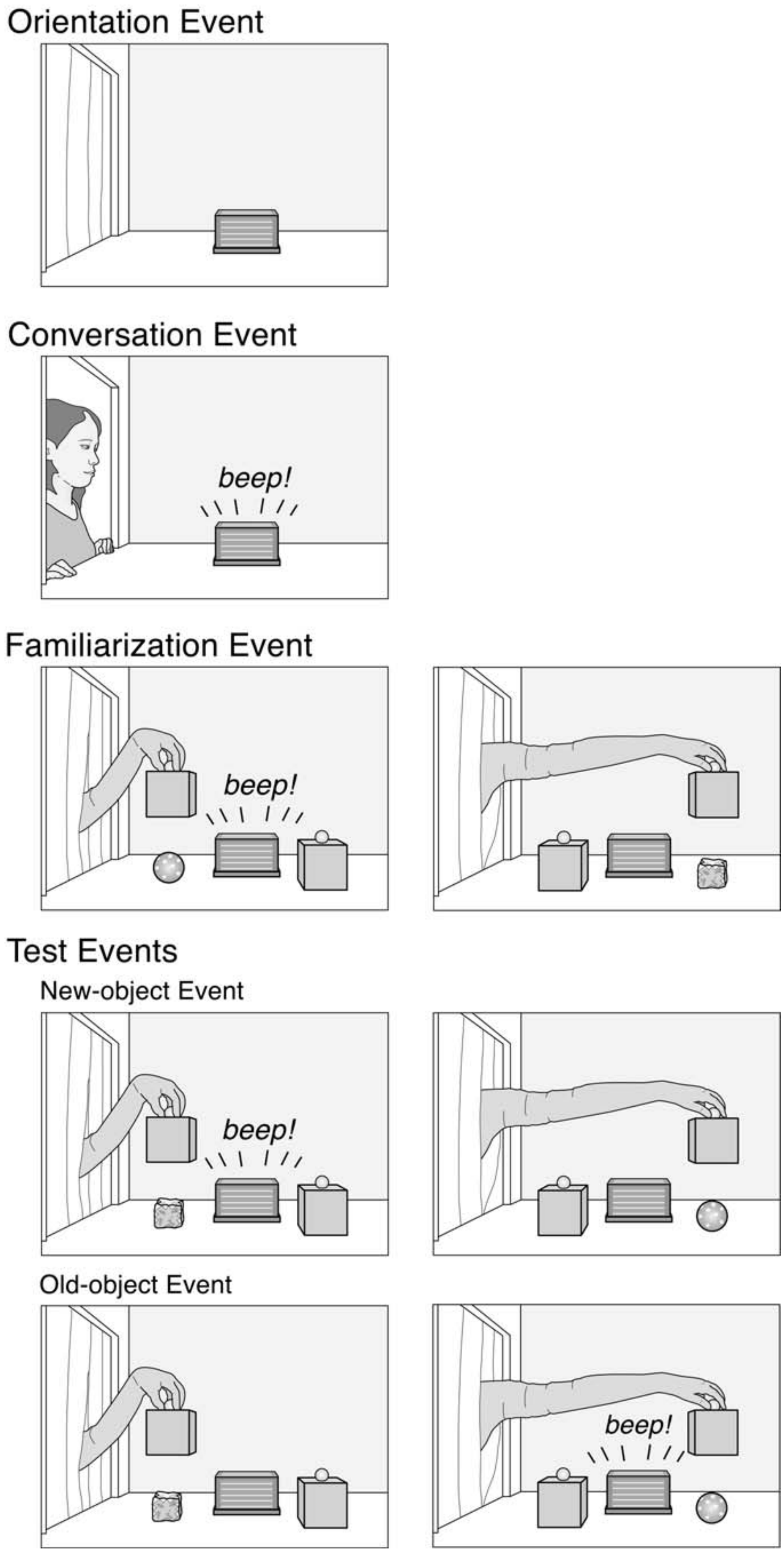
Inert Condition
Self-propelled Condition
Conversation Event
beep!
Familiarization Event
Test Event



Orientation Event
Conversation Event
beep!
Familiarization Event
beep!
Test Events
New-object Event
beep!
Old-object Event
beep!