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INFANTS' REASONING ABOUT
SELF-PROPELLED OBJECTS, AGENTS, AND ANIMALS

BY

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DISSERTATION

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ABSTRACT

In the present research, we investigated young infants' concepts of self-propelled object, agent, and animal through three research projects. In Chapter 2, we examined infants' concept of self-propelled object, specifically, whether 5-month-olds expect a self-propelled object to produce changes in its parts. We found that 5-month-olds understand that a self-propelled object can use its internal energy to produce orientation and position changes but not location and appearance changes in its parts. In Chapter 3, we examined infants' concept of agent, particularly, whether infants believe that an agent can be inert. The results indicated that 14-month-olds believe that an agent can be inert, suggesting that self-propulsion is not necessary for infants to identify an object as an agent. In Chapter 4, we asked whether infants have any quasi-biological expectations about animals. The results suggest that 7-month-olds expect the inside of an animal to be full as opposed to be hollow. Together, these results support the core-concept view which states that infants divide objects into broad, abstract categories in accordance with the causal principles in specific reasoning domains.

To my dearest Father, Mother, and Brother

TABLE OF CONTENTS

CHAPTER1: INTRODUCTION	1
1.1. Views of the development of categorization in infancy	2
1.2. The links between self-propelled objects, agents, and animals	6
1.3. An evidence-based identification	9
1.4. The present research	10
CHAPTER2: CAN A SELF-PROPELLED OBJECT PRODUCE CHANGES IN ITS PARTS	11
2.1. Internal energy enables self-propelled objects to change their own motion states ..	14
2.2. Internal energy enables self-propelled objects to change their locations	15
2.3. Internal energy enables self-propelled objects to control other objects' motion	18
2.4. The present research	22
CHAPTER 3: CAN AN AGENT BE INERT? 14-MONTH-OLD INFANTS' REASONING ABOUT AGENCY WITHOUT MOTION CUES	52
3.1. What objects can be agents?	52
3.2. What information do infants use to identify an agent?	53
3.3. Inert agent	59
3.4. The present research	59
CHAPTER 4: CAN AN ANIMAL BE HOLLOW? 7-MONTH-OLD'S EXPECTATIONS ABOUT THE INSIDES OF ANIMALS.....	80
4.1. Animals as self-propelled agents	81
4.2. Animals as more than self-propelled agents	84
4.3. The present research	88
CHAPTER 5: CONCLUSION	100
5.1. Infants' expectations about self-propelled objects, agents, and animals	101
5.2. The relation between the concepts of self-propelled object, agent, and animal	105
5.3. Infants' understanding of objects' internal attributes	106
FIGURES.....	109
REFERENCES	132

CHAPTER 1

INTRODUCTION

After birth, infants have to learn an enormous amount of knowledge about the real world. How infants acquire this knowledge and make sense of the events in the real world has puzzled psychologists and developmental researchers for decades. During development, infants need to classify different objects and make distinctions between them. These distinctions help infants sort their knowledge about the world around them and organize it in a meaningful way.

On one hand, researchers are interested in whether and how infants and young children form basic object categories, such as cats, dogs, chairs, beds, and so on (e.g., Eimas & Quinn, 1994; Quinn, 2002; Quinn & Eimas, 1996, 1998; Rakison, 2005; Rakison & Butterworth, 1998). For example, Quinn and Eimas (1996) habituated 3- and 4-month-old infants to pictures of different cats. In the test trials, the infants dishabituated to pictures of a dog, lion, or other animal, but not to pictures of novel cats, suggesting that during the habituation trials the infants formed a category of “cat” which included the novel cats but excluded dogs, lions, and other animals. Using a similar method, they found that 3- and 4-month-old infants could form categories of different animals, like horses, birds, dogs, etc.

On the other hand, researchers explored whether infants and young children divide objects into broad and abstract categories, such as inanimate objects, agents, and living things (e.g., Arterberry & Bornstein, 2001, 2002; Carey, 1999; Gelman, 1990, 2002; Gelman, Durgin, & Kaufman, 1995; Leslie, 1984, 1994; Gottfried & S. Gelman, 2005; Mandler, 2010, McDonough and Mandler, 1998; Quinn & Oates, 2004; Quinn, 2005; Rakison & Poulin-Dubois, 2001, 2002; S. Gelman & Gottfried, 1996; Subrahmanyam, Gelman & LaFosses, 2002). These abstract categories are crucial for infants and young children to make correct inferences about unfamiliar

objects in certain categories. For example, both inanimate objects and living things have heights, weights, and colors, but only living things can eat, drink, and sleep. The present research focused on infants' broad, abstract categories.

1.1. Views of the development of categorization in infancy

Researchers have at least three different views on how infants form these broad, abstract categories. Each of them will be discussed in the following section. The first view, an experience-based view, is proposed by those advocates who believe that infants initially lack the abstract conceptual knowledge on which broad object categories might be based. With experience, infants gradually associate groups of objects with similar perceptual properties together to form categories (e.g., Eimas & Quinn, 1994; Quinn & Oates, 2004; Quinn, 2005; Rakison, 2005; Rakison & Poulin-Dubois, 2001, 2002). Infants categorize objects along many perceptual attributes, such as texture, shape, parts, facial features, behaviors, and so on. Rakison and Poulin-Dubois (2001) suggest that infants start to discriminate particular animate- from inanimate-related motions at around 6 months of age. Infants gradually construct a notion of animacy over the first 2 years of life through a process of continual representational enrichment. They also suggest that the type of motion in which objects engage is critical for infants to form the distinction between animate and inanimate objects. Cues associated with type of motion include (1) onset of motion (self-generated or caused movement), (2) line of trajectory (smooth or irregular), (3) form of causal motion (action at a distance or action with contact), (4) pattern of interaction (contingent or non-contingent), and (5) type of causal role (agent or recipient). Rakison and Poulin-Dubois propose that infants learn through experience to use these motion criteria to distinguish animate from inanimate objects. For example, infants' repeated

observations of humans, cats, and dogs make them notice that all of these entities are capable of self-generated motion, which is one criterion for the animate-inanimate distinction.

Rakison (2005) also found that infants associate objects' parts with relevant motions, such as legs with irregular motions. He showed 18-month-old infants an exemplar, either from the category of animals (e.g., a cat) or from vehicles (e.g., a car), and its motions, and then gave the infants another four objects (e.g., a dog, a bed, a dolphin, and a truck) to imitate the motions of the exemplar. He found that the infants relied on objects' functional parts to imitate the motions modeled with the exemplar from the two different categories. As an example, the infants were more likely to choose the dog and the bed, rather than the dolphin and the truck, to imitate the cat's motion because they share the same kind of body parts, legs. At about 22 months of age, the infants in his research generated the motion of an exemplar (e.g., a cat) by choosing the exemplars from the same category members (e.g., a dog and a dolphin). Based on these findings, Rakison concluded that infants associate objects' parts with the motion kinds first, and when older they develop a more abstract category which predicts what kind of motions an object can exhibit.

The second view, proposed by Mandler (2010), suggests that the formation of category is based on a kind of analog representation—spatial image schema—that is constructed through a perceptual meaning analysis of the spatiotemporal information of objects and events. One of these early concepts is animals which are seen as things that start to move on their own and interact contingently with other objects from a distance. In contrast, inanimate objects are described as things that do not move by themselves (they start moving only when contacted by another object) and do not interact with other objects from a distance. According to this view, early concepts are composed from one or more pieces of spatial primitives, such as Path

(referring to an object's motion through space), Start Path (referring to the start of motion along a path through space), Contact (referring to one object touching another), and Link (referring to interaction). A negative sign (-) is used to express absence of some spatial information. For example, animals start moving by themselves (Start Path, -Contact), whereas inanimate objects start moving when contacted by another object (Start Path, Contact). Mandler suggests that these general concepts limit the way that infants learn about relevant properties of the corresponding categories. There is not much direct empirical evidence to support the existence of image schemas. Most of the experimental evidence is obtained from research on infants' understanding of the general concepts of animals and vehicles. For instance, Mandler and McDonough (1996) showed 14-month-old infants events in which an experimenter demonstrated two animal-appropriate actions (drinking and sleeping) using a replica of a dog (e.g., a dog drinking from a cup) and two vehicle-appropriate actions (riding and keying) to a replica of a car (e.g., a car giving a ride). Next, the infants were given similar and dissimilar exemplars from the same and from the different category (e.g., if the infants were shown a dog at the beginning, then in the test they would be given a similar exemplar, like "a cat", and a dissimilar exemplar, like "a bird"; the infants were also given two distracters from the other category, such as an airplane and a bus). Mandler and McDonough recorded whether the infants generated the actions demonstrated with the exemplars from the same or the different category. They found that the infants imitated the actions with both similar and dissimilar exemplars within the same category, but rarely applied the actions to the distracters from the different category. With infants as young as 9 months of age, they found similar results (McDonough & Mandler, 1998). Based on these results, they concluded that at least 9-month-old infants possess abstract concepts of animal and vehicle that guide their understanding of these categories.

The third view, a core-concept view, is suggested by researchers who believe that infants are born with domain-specific causal principles that lead them to divide objects into different categories (Carey, 1999; Gelman, 1990, 2002; Gelman et al., 1995; Leslie, 1984, 1994; S. Gelman & Gottfried, 1996; Gottfried & S. Gelman, 2005; Subrahmanyam et al., 2002). According to this view, in different domains, infants may categorize objects differently in accordance with the corresponding causal principles. In the physical-reasoning domain, researchers (e.g., Gelman, 1990, 2002; Leslie, 1984, 1994, 1995) have proposed that infants interpret physical events in accordance with a notion of energy. According to this view, infants attend to the source of the energy which changes objects' motion states. Infants tend to view objects as self-propelled if they change their motion states without a source of external force. When objects' motion states are changed by an external source of force, infants tend to think of the objects as inert. Infants thus endow a self-propelled but not an inert object with an internal energy. Previous research involving self-propelled and inert objects suggests that even young infants hold different expectations for self-propelled and inert objects and believe that a self-propelled object can move on its own, can resist an external force so as to not move when hit, can remain suspended when released in midair, can hold other objects, and can cause other objects to move (e.g., Leslie, 1984; Leslie & Keeble, 1987; Luo, Kaufman, & Baillargeon, 20096; Oakes, 1994; Spelke, Phillips, & Woodward, 1995; Woodward, Phillips, & Spelke, 1993; Saxe, Tenenbaum, & Carey, 2005; Saxe, Tzelnic, & Carey, 2007).

In the psychological-reasoning domain, research in the past three decades has suggested that young infants understand and predict others' behaviors in accordance with their motivational states, such as dispositions, preferences, and goals (e.g., Bellagamba, & Tomasello, 1999; Carpenter, Aktar, & Temasello, 1998; Gergely, Nadasdy, Csibra, & Biro, 1995; Luo &

Baillargeon, 2005; Meltzoff, 1995; Woodward, 1998; Woodward & Guajardo, 2002), informational states, like inferences and perceptions (e.g., Luo & Baillargeon, 2007; Luo & Johnson, 2009; Luo & Beck, 2010), and fictional states, like false perceptions and false beliefs (e.g., Onishi & Baillargeon, 2005; Scott, & Baillargeon, 2009; Surian, Caldi, & Sperber, 2006). For young infants, agents may be objects that detect their environment and pursue their goals. Infants seem to distinguish agents from other objects in terms of a notion of internal states. Researchers are still debating about what information infants use to decide whether an object has internal states. Previous research has suggested that some behavioral cues might be helpful in the identification of an agent, such as choosing goals to pursue, choosing means to pursue a goal, and taking turns in a conversation with a person (e.g., Csibra, 2008; Johnson, Shimizu, & OK, 2007) In Chapter 3, we will discuss further what behavioral cues infants use to identify an agent.

The biological-reasoning domain focuses on understanding biological events and processes, such as growth, death, biological transformations, and so on. Researchers differ on when the biological-reasoning domain emerges in children's knowledge system, where it arises from and how it develops over time (e.g., Carey, 1985, 1999; Hatano & Inagaki, 1994; Keil, 1994; R. Gelman, 1990; S. Gelman & Wellman, 1997). But in order to understand biological phenomena, young children have to make a distinction between animals and other objects. According to the core-concept view, if infants have a separate biological-reasoning domain, they may have a core concept of animals and hold quasi-biological expectations about animals.

1.2. The Links between self-propelled objects, agents, and animals

In previous research, the distinction between animate and inanimate objects has been widely used. However, the definitions of animate object and inanimate objects seemed to be somewhat divergent in different research. Animate objects, in most prior research work, referred

to objects that are self-propelled and agentive and have biological properties such as faces, fur, and biological motions. But in some other research animate objects referred to the objects that can start to move on their own without any biological properties. If the core-concept view is right, it is necessary to make a distinction among self-propelled objects, agents, and animals when we try to explore how infants understand events in different domains.

In the present research, self-propelled objects referred to objects that possess internal energy and can control their own motions. The notion of internal energy leads infants to distinguish self-propelled from inert objects. To make sense of some physical events, infants do not need to know whether an object is alive, or whether it can grow, but they need to consider whether the object can move on its own or not. For example, infants believe that both humans and self-propelled boxes can initiate their motions, resist external forces, and hold objects in midair, suggesting that infants view both as self-propelled objects rather than differentiating them as animate and inanimate objects in these physical events. Therefore, though related, the distinction between self-propelled and inert object is not interchangeable with the animate-inanimate distinction. Self-propelled objects refer to objects which can move on their own, such as humans, animals, cars, self-propelled toys, and so on. Inert objects refer to objects which cannot move on their own, such as chairs, tables, computers, keys, and so on.

In the psychological-reasoning domain, the core concept is agent. In the biological-reasoning domain, the core concept is animal. It is not difficult to notice that the category of self-propelled objects is related to the categories of agents and animals. For example, humans are considered as self-propelled objects, intentional agents, and bipedal animals. Other animals can also be categorized into these three categories. But the overlaps among these categories do not mean that they are interchangeable. Infants encounter not only physical but also psychological

events in daily life. When encountering psychological events, infants need to interpret and predict an agent's behavior in accordance with notions of perception and goal. Premack (1990) proposed that infants categorize a self-propelled object as an intentional object, interpret its movement in space in terms of goals, preferences, and other mental states. According to this proposal, it is objects' motion pattern that triggers infants' psychological reasoning regardless of whether the objects resemble humans or not. Recent research, however, has suggested that self-propelled motions are not sufficient for infants to view an object as an agent and interpret its action as goal-directed (e.g., Csibra, 2008; Johnson et al., 2007; Shimizu & Johnson, 2004). Moreover, recent research also imply that self-propulsion is not necessary for infants to identify one object as an agent (e.g., Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Biro & Leslie, 2007). These results suggest that for infants not all self-propelled objects are agents and not all agents are self-propelled.

Another related category of self-propelled objects is animal. As adults, we know that most animals can move on their own. But we also know that not all self-propelled objects are animals. Do infants realize that there exist differences between self-propelled objects and animals? Animals usually are agents which pursue their goals and detect their environment. Do infants also realize that there is a relation between animals and agents? According to a recent proposal, infants may view animals as self-propelled agents (e.g., Mandler, 2010). On one hand, infants may view animals only as the simple combination of self-propelled objects and agents and expect them to have internal energy and internal states. There are no more expectations relevant to the biology. On the other hand, infants may view animals as more than self-propelled agents. Previous research suggests that young children distinguish animals from other objects and hold biological expectations about animals. For example, they understand that animals have

to make of biological stuff (e.g., Massey & Gelman, 1998), and talk about animals in terms of their biological features such as muscles, bones, and blood, and biological notions such as alive and living (e.g., Subrahmanyam et al., 2002). Young infants may not have a clear understanding about what animals are made of, but they may have some quasi-biological expectations about animals. If this is the case, then it means that infants' concept of animals is separate from their concepts of self-propelled object and agent.

1.3. An evidence-based identification

If infants have different core concepts in specific reasoning domains, the question is how infants identify the ontologically relevant objects in each domain. Particularly, how do infants construe a novel object as inert or self-propelled in the physical-reasoning domain, as an agent in the psychological-reasoning domain, and as an animal in the biological-reasoning domain? We believe that the identification of ontologically relevant objects in specific domains is based on whether infants receive clear evidence in terms of the causal principles in the given domain. In the physical-reasoning domain, infants view an object as self-propelled according to the evidence that it possesses internal energy. If there is no unambiguous evidence of possessing internal energy, infants would view the object as inert by default. The evidence includes, initiating a motion, resisting to be moved when hit, floating in midair when released, reversing the motion trajectory, and so on.

As we discussed above, the concepts of self-propelled objects, agents, and animals are related but not identical. Therefore, the evidence of self-propulsion would not be critical when infants identify ontological entities in the other two domains. In the psychological-reasoning domain, infants collect evidence to see whether an object has internal states. Without clear evidence of internal states, a self-propelled object would not be viewed as an agent. In the

biological-reasoning domain, if infants have one and they believe animals are self-propelled agents, they might collect both evidence of internal energy and internal states to identify an object as an animal. We will discuss more about what evidence infants use to identify an object as an agent and an animal in Chapters 3 and 4.

1.4. The present research

The present research is composed of three related research projects. First, we aimed to investigate further young infants' expectations for self-propelled objects. Following existing research, we asked whether infants believe that self-propelled but not inert objects can produce changes in their parts. At the same time, we examined whether infants believe that self-propelled objects cannot produce certain changes due to the limitation of an application of internal energy. In Chapter 2, we conducted four experiments in which infants were shown novel self-propelled objects with prominent parts and asked whether infants believe that these objects can use their internal energy to produce appearance, location, position, and orientation changes in their parts.

In Chapter 3, we aimed to investigate deeper infants' concept of agents. In particular, we asked whether young infants believe that an inert object can be an agent as long as it provides evidence of possessing internal states. We designed two experiments to investigate whether self-propulsion is necessary for an object to be viewed as an agent.

In Chapter 4, we started to explore infants' concept of animals. In one experiment, we asked whether infants have any quasi-biological expectations for an animal, specifically, whether they expect an animal to be full inside as opposed to be hollow.

In the last chapter, we discuss the relationships between infants' concepts of self-propelled objects, agents, and animals.

CHAPTER 2

CAN A SELF-PROPELLED OBJECT PRODUCE CHANGES IN ITS PARTS?

In the past several decades, researchers have investigated infants' understanding of physical events involving self-propelled and inert objects. It has been found that, although infants often have the same expectations for self-propelled and inert objects, in some physical events infants hold different expectations for self-propelled and inert objects (e.g., Golinkoff, Harding, Carlson, & Sexton, 1984; Lesile, 1984, 1994, 1995; Leslie & Keeble, 1987; Luo et al. , 2009; Oakes, 1994; Spelke et al., 1995; Woodward et al., 1993). On one hand, infants understand that both self-propelled and inert objects are physical entities that are subject to the principle of persistence (e.g., Baillargeon, 2008; Baillargeon, Wu, Yuan, Li, & Luo, 2009), which states that objects exist continuously in space and time, retaining their physical properties as they do so. For example, 2.5-month-olds expect both self-propelled and inert objects to move continuously through space, and are surprised to see the objects disappear behind one occluder and reappear from behind another occluder without traveling through the gap between them (e.g., Aguiar & Baillargeon, 1999; Wilcox, Nadel, & Rosser, 1996). 5-month-olds expect tall self-propelled and inert objects to protrude behind a short occluder, and are surprised to see them fully hidden behind the occluder (e.g., Baillargeon & Graber, 1987; Hespos & Baillargeon, 2001).

On the other hand, previous research also implies that infants hold different expectations for some physical events involving self-propelled and inert objects. For example, Woodward et al. (1993) conducted an experiment which provided direct evidence that infants expected different outcomes when self-propelled and inert objects were involved in a collision event. They showed videotaped events to 7-month-olds who were randomly assigned to an inert or a self-propelled condition. In the inert condition, the infants were first familiarized with an event in

which a human-sized pillar moved towards a large occluder from the left side of the TV screen and then disappeared behind the occluder; after a short delay, a second pillar, which was partially visible on the right side of the occluder, started to move to the right of the screen. Following the familiarization trials, the occluder was removed and the infants saw two test events involving fully visible objects moving in the same manner as before. The infants in the contact event saw the two pillars make contact before the second one started to move, whereas the infants in the no-contact event saw a similar event except that the two pillars did not make contact. The infants in the self-propelled condition saw similar events except that a man and a woman replaced the two pillars. The authors found that the infants in the inert condition looked reliably longer at the no-contact than at the contact event, whereas those in the self-propelled condition looked about equally at both test events. The results suggested that the infants viewed the pillars as inert objects and believed that inert objects required contact to be moved, but understood that the humans were self-propelled and could start to move without direct physical contact.

These and other previous research findings suggest that infants from early on distinguish self-propelled from inert objects in physical events. The advocates of the core-concept view (e.g., Gelman, 1990, 2002; Leslie, 1994, 1995) have suggested that infants' different expectations for self-propelled and inert objects may originate from infants' notion of internal energy. Infants would not view an object as self-propelled unless it provides evidence that it possesses internal energy. When infants watch an object begin to move or change its direction, they attend to the cause responsible for the change in the object's motion state and determine whether the cause is internal or external to the object. If the motion cannot be explained by an external cause or force, infants would view the object as self-propelled and endow it with an internal source of energy. Recent research (Mascalzon, Regolin, & Vallortigara, 2010) found that even new hatched chicks

distinguished self-propelled from inert objects. Moreover, the chicks did not view any moving objects as self-propelled, but viewed objects as self-propelled when there was unambiguous cues that the objects engaged in self-generated motions. In the experimental condition of Mascalon and her colleagues' study, new hatched chicks were familiarized with an animated event in which one object (object A) started to move and contacted a second, stationary object (object B): immediately after the contact, object B started to move and object A became stationary. The chicks showed a clear preference for object A in the test phase. In the no-contact condition, the chicks saw the same event except that there was no contact before object B started to move. In the test phase, the chicks showed no clear preference for either of the objects. These results suggested that (1) the chicks in the experimental condition, viewed object A but not object B as self-propelled because it initiated its own motion and (2) the chicks in the no-contact condition viewed both objects as self-propelled because they both initiated their own motion. The chicks were also shown another animated event identical to that in the experimental condition except that two opaque screens hid the beginning of object A's motion path and the end of object B's motion path. In this condition, it was unclear whether object A started to move on its own or if an external force out of view caused it to move; therefore, there was no clear evidence that object A was self-propelled. As for object B, it moved only after object A contacted it, so its motion could be explained by an external force; therefore, it too could be viewed as inert. The results showed that the chicks again showed no preference for either object, suggesting that they did view both objects as inert.

Besides initiating a motion, other behavioral cues can be used to determine whether an object is self-propelled or inert, such as reversing motion spontaneously, resisting external forces, and floating in midair when released. For young infants, both human and nonhuman objects,

such as dogs, cats, self-propelled cars, and the self-propelled pillars, balls, and boxes used in previous research are self-propelled objects because they provide clear evidence that they possess an internal source of energy. Moreover, young infants understand that this internal source of energy enables a self-propelled object to control its own or other objects' motion. In contrast, they believe that inert objects cannot move without external causes.

2.1. Internal energy enables self-propelled objects to change their own motion states

Recent research suggests that young infants endow a self-propelled object with internal energy which enables it to control or change its own motion states. Take a recent series of experiments by Luo et al. (2009) as an example. In their experiments, they investigated what 5- to 6-month-olds expect a self-propelled box to be capable of. They first examined whether 5-month-old infants would believe that a self-propelled but not an inert object could reverse its motion direction. They randomly assigned 5-month-olds into an inert or a self-propelled condition. In the inert condition, the infants sat in front of a large apparatus whose right side was occluded by a large screen. The infants first received familiarization trials in which they saw a small red box resting on the left side of the apparatus; an experimenter's gloved hand hit the box and apparently caused it to move toward the right side of the apparatus. The box continued to move until it disappeared behind the large screen at the right side of the apparatus. After a few seconds, the box reappeared from behind the large screen and traveled back to its starting position. This entire event cycle was repeated until the trial ended. After the familiarization trials, the large screen was removed from the apparatus and the infants saw a near-wall and a far-wall test event on alternate trials. In the near-wall event, the infants saw the gloved hand hit the box, which then moved to the right side of the apparatus, hit the wall partition, reversed direction as though bouncing back, and returned to its original position. In the far-wall event, the infants saw

a similar event except that the wall partition was placed farther to the right and the box reversed its direction spontaneously without hitting the wall. The infants in the self-propelled condition saw the same events except that the box initiated its own motion and the hand remained stationary on the apparatus floor (see Fig. 1). Luo et al. found that the infants in the inert condition were surprised to see the box reverse the direction spontaneously in the far-wall event, and looked longer at the far- than at the near-wall event. In contrast, the infants in the self-propelled condition were not surprised to see the box reverse direction spontaneously in the far-wall event, and looked about equally and equally short at the far- and near-wall test events. These results suggested that the infants in the inert condition, (1) viewed the box as an inert object because there was no evidence that it was able to move on its own, (2) expected the box to move in a smooth path without abrupt deviation, and hence (3) were surprised to see the box reverse its direction spontaneously without hitting the wall. In contrast, the infants in the self-propelled condition, (1) considered the box as a self-propelled object because it initiated its own motion, (2) believed that the box could use its internal energy to control its motion path, and hence (3) were not surprised to see the box reverse its direction spontaneously.

2.2. Internal energy enables self-propelled objects to change their locations

In the same series of experiments, Luo and her colleagues (2009) also examined whether 6-month-olds believe that a self-propelled object can change its location when out of sight. They assigned 6-month-olds to an inert or a self-propelled condition. In the inert condition, the infants were familiarized with an event in which a box emerged from behind a large screen, traveled a short distance, until it hit the right wall of the apparatus and reversed direction, as though bouncing back, to return behind the screen. In the self-propelled condition, the infants saw a similar familiarization event except that the right wall of the apparatus was placed farther away

from the left wall, so that the box appeared to reverse direction spontaneously without hitting the wall. The rationale is that if infants assume that an object is inert until proven otherwise, then the infants should view the box as inert when its reversal could be explained by hitting the wall, and as self-propelled when it could not.

During test, half the infants in each condition saw a one-screen event, and half saw a two-screen event. In both test 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 (see Fig. 2).

Luo et al. (2009) found that 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 indicated that the infants in the inert condition (1) viewed the box as an inert object because there was no clear evidence that it was able to move on its own, (2) detected a persistence violation in the one- and two-screen events because in both events the box inexplicably disappeared and reappeared, and therefore (3) were surprised to see both test events. In contrast, the infants in the

self-propelled condition (1) considered the box as a self-propelled object because it reversed direction spontaneously, (2) inferred that the box surreptitiously moved behind the second screen when it “disappeared” and returned from behind the second screen when it “reappeared” in the two-screen event, and hence (3) found the one- but not the two-screen event surprising.

Wu, Luo, and Baillargeon (2006, 2010) found that younger infants, 4-month-olds, also endow self-propelled but not inert objects with internal energy and believe that this internal energy enables self-propelled objects to alter their locations in occlusion events. 4-month-old infants were randomly assigned to an inert or a self-propelled condition. The infants in the inert condition faced a wide screen with two closed windows located a short distance apart. The infants were familiarized with an event in which a gloved hand lifted a red column above the screen, between the windows, tilted it to the left and right, and then lowered it back behind the screen; next, the hand lifted and lowered a black ball, in the same location as the column. The infants in the self-propelled condition saw the same familiarization event except that the objects moved by themselves. Next, all infants saw two kinds of test events. In the two-window event, the 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 (see Fig. 3).

The results indicated that 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 at both test events. These and control results suggested that the infants in the inert

condition (1) believed that the inert objects were subject to the principle of persistence, (2) expected the inert column and ball to occupy different locations behind the screen, and (3) were surprised to see the violation of the persistence principle: the inert column and ball occupied the same space behind the same window. In contrast, the infants in the self-propelled condition (1) understood that the self-propelled column and ball were also subjected to the principle of persistence, (2) endowed the objects with an internal source of energy which enabled them to move behind the screen, and (3) generated an explanation for the one-window event: they inferred that the column and ball switched positions behind the screen when the windows were closed.

These and other findings suggested that young infants distinguish self-propelled from inert objects in physical events, endow self-propelled objects with an internal source of energy, and believe that this internal energy enables a self-propelled object to control its own motion states: it can initiate its own motion, change its motion path, change its location when out of sight (such as disappearing from behind one of the two overlapping screens), remain stationary when hit, remain suspended when released in midair, and so on. At the same time, infants understand that self-propelled objects are subject to the principle of persistence, but the application of internal energy sometimes leads to possible explanations for events which appear to violate the principle of persistence.

2.3. Internal energy enables self-propelled objects to control other objects' motion

Previous research also suggests that young infants understand that self-propelled objects can use their internal energy to exert force on other objects and cause them to change their motion states, such as causing other objects to move (e.g., Leslie & Keeble, 1987) and holding other objects in midair without support (e.g., Li, Baillargeon, & Needham, 2006, 2008). Infants

realize that self-propelled objects are able to not only move themselves, but also, as causal entities, move other recipients in physical events. To illustrate, Saxe et al. (2005) assigned 12-month-olds in a hand or a train condition. In both conditions, the infants were first habituated to an event in which a beanbag was thrown over a wall onto the center of a stage, either from the left or the right side of the stage. In the test phase, after the beanbag landed on the stage, the infants in the hand condition saw a human arm enter the stage from the side of the origin of the beanbag (same-side event), or from the opposite side of the stage (different-side event). The infants in the train condition saw similar events except that the human arm was replaced by a toy train that protruded from the side of the stage. They found that the infants in the hand condition looked longer at the different- than at the same-side event, whereas the infants in the train condition looked about equally at both test events. These results indicate that the infants (1) inferred that an unseen entity threw the beanbag over the wall on the stage, (2) expected the causal entity to be on the side of origin of the beanbag, and (3) construed the hand (self-propelled) but not the toy train (inert) as the potential casual entity which threw the beanbag. In another condition, infants first were familiarized for 20 seconds with a furry puppet which had two legs and googly eyes and jumped slowly across the stage. Then, infants saw the same events as those in the hand condition except that the beanbag was replaced by the puppet. Unlike the infants in the hand condition, the infants in this condition looked about equally at the same- and different-side events, suggesting that infants (1) construed the puppet as a self-propelled object, (2) understood that it could jump over the wall without an external cause, and therefore (3) they did not infer an external cause, such as the hand, from the same side of the origin of the puppet. Using a slightly different procedure, Saxe et al. (2007) replicated the results in a recent research. Saxe et al. first familiarized 9.5-month-old infants to 2 beanbags on the stage for 20 seconds. In

the habituation trials, the left and right sides of the stage were occluded by two upright screens. On each habituation trial, the infants watched an event in which one of the two beanbags was thrown onto a piece of white cloth at center of the stage from either behind the left screen or the right screen. On test trials, the screens were lowered to reveal a hand on one side and a toy train on the other. Then, the screens were raised up, and a beanbag emerged either from the hand side or the train side. The authors found that the infants looked longer at the test trials in which the beanbag emerged from the train side than from the hand side, suggesting that they expected the hand but not the train to be the external cause of the motion of the beanbag. Moreover, when the human hand was replaced with a self-propelled puppet, the infants still looked longer at the test trials in which the beanbags came from the train side than from the puppet side, suggesting that like human hand, the self-propelled puppet was more likely to be construed by infants as a causal entity for the motion of the beanbag. Together, these results suggest that young infants believe that a self-propelled object is more likely than an inert, stationary object to be a cause of the motion of an inert object.

Young infants believe that a self-propelled object can not only cause another object to move, but also hold another object in midair without support. Recent research by Li et al. (2006, 2008) examined 4.5- to 5.5-month-olds' understanding of "support". The infants saw two test events in which a yellow platform rested on an apparatus floor; a yellow box was at the bottom of the platform's right wall and a gloved hand placed a green box against the center of the platform's right wall. In the supported event, the yellow box was sufficiently tall that the green box could rest on it when placed against the platform. In the unsupported event, the yellow box was short so that the green box rested above it. They found that the infants looked longer at the unsupported than at the supported event. In a following experiment, the infants first were

familiarized with an event in which the big yellow platform was moving back and forth on the apparatus floor while the small green box remained stationary in front of the apparatus. Then, the infants in the experimental condition saw the same supported and unsupported events as those in the previous experiment. They found that infants looked about equally at the supported and unsupported events, suggesting that infants viewed the big yellow platform as a self-propelled object which had internal energy to hold the small green box in midair in the unsupported event. To exclude the argument that the infants were confused by the moving platform in the experimental condition, they conducted a control condition. After viewing the familiarization event, the infants in the control condition saw similar test events except that the yellow platform stood 10 cm to the left of the yellow box. The short and tall yellow boxes were still in their original location and the hand performed the same actions as before. There was thus a gap between the yellow platform and the green box. The infants now looked reliably longer at the unsupported than at the supported event. These and other control results suggest that infants (1) endow a self-propelled but not an inert object with an internal energy which enables it to hold another object, and (2) realize that a self-propelled object can only hold another object with direct contact.

The evidence reviewed above suggests that young infants endow self-propelled but not inert objects with internal energy and they take this into account when an application of internal energy could help explain the outcome of a physical event. They understand that an application of internal energy can explain some outcomes, such as disappearing behind one of two overlapping screens or holding another object in midair. At the same time, however, infants view as impossible other changes that cannot be explained by an application of internal energy, such as disappearing into thin air (e.g., Luo, et al., 2009), or changing appearance (e.g., Wilcox, 1999;

Wu, et al., 2006, 2010). In a series of experiments, Wilcox (1999) presented 4.5- to 11.5-month-old infants with an event in which a self-propelled object moved toward a narrow occluder which was too narrow to hide two objects at once. The object disappeared behind one side of the occluder, and then, after a short time interval, a different object emerged from behind the other side of the occluder. Wilcox found that infants at 4.5 months of age were surprised to see that a self-propelled ball moved behind the occluder and a smaller ball or a box moved out from the other side; at 7.5 months of age, they were surprised if the self-propelled ball changed its pattern when passing from behind the occluder; and at 11.5 months of age they were surprised if a red ball disappeared behind the occluder and a green ball reappeared from behind the occluder.

Therefore, young infants understand that the application of internal energy cannot result in a real persistence violation in a physical event: specifically it cannot explain size, shape, pattern and color changes in a self-propelled object. That is, infants understand that the application of internal energy has its limitations.

2.4. The present research

In the present research, we were interested in whether young infants understand that a self-propelled object can use its internal energy to control its parts. Particularly, do young infants believe that the application of internal energy can enable a self-propelled object to produce some but not other changes in its parts?

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. In the present research, 5-month-old infants saw a box with one or two prominent parts moving on the apparatus floor. According to previous research, we believed that they would view the box and its parts as a single, connected object. In four experiments, we examined infants' responses to events in which one or more parts of the box changed while the box was briefly hidden. In designing these experiments, we considered four different ways in which parts might change; for ease of communication, we refer to these as changes in appearance, location, position, and orientation. An appearance change is one in which a part alters its size, shape, pattern, and color; 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 shifts 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.

Experiment 1

Experiment 1 examined 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, 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). As mentioned above, prior research

indicates that, by 4.5 months of age, infants have identified height, width, and shape as relevant variables in occlusion events (e.g., Baillargeon & DeVos, 1991; Wang & Baillargeon, 2006; Wang, Baillargeon, & Brueckner, 2004; Wilcox, 1999) and thus detect appearance changes involving these variables in these events.

Experiment 1 built on these results and asked whether infants would realize that not even a part of a self-propelled box could change its appearance (i.e., size, shape, pattern, and color) while the box was briefly occluded. We tested 5-month-old infants with a self-propelled blue box which had a single yellow jagged flap or a red semi-circle flap extending from its upper left edge, parallel to the apparatus floor (see Fig. 4 A-B). The flap roughly looked like a large ‘tail’ extending either behind or above the back of an animal. In the familiarization phase, the box emerged from behind a large screen on the apparatus floor, traveled a short distance, and then reversed its direction spontaneously to return behind the screen, thus establishing that it was self-propelled. In the test phase, the box stood stationary behind a small screen. The screen was briefly raised to hide the object and then lowered again. The appearance of the box’s flap either remained the same (no-change event) or was altered (change event) (see Fig. 5). We predicted that the infants would realize that a part of a self-propelled box could not alter its appearance in size, shape, pattern, and color, and hence they would be surprised when it did. Therefore the infants who saw the change event should look reliably longer than those who saw the no-change event.

Method

Participants

Participants were 16 healthy term infants, 7 male and 9 female, ranging in age from 4 months, 10 days to 5 months, 22 days ($M = 5$ months, 4 day). Another 4 infants were tested but

eliminated, 2 because they were distracted, and 2 because their looking times fell beyond 2.5 standard deviations from the mean of their condition. Half the infants saw the box with a yellow jagged flap in the familiarization trials, and half saw the box with a red semi-circle flap. Within each group, half the infants saw the change test event, and half saw the no-change test event.

Apparatus

The apparatus consisted of a wooden display booth 125 cm high, 164 cm wide, and 78 cm deep that was positioned 76 cm above the room floor. The infant faced an opening 46 cm high and 157.5 cm wide in the front wall of the apparatus; between trials, a curtain consisting of a muslin-covered frame, 56.5 cm high and 163 cm wide, was lowered in front of this opening. The side walls of the apparatus were painted white and the floor was covered with black contact paper. The back wall was constructed of foam board and was covered with a grey granite-patterned contact paper; at the bottom of the wall, across its entire width, was a 0.5 cm gap filled with black felt.

The box used in the experiment was 12 cm high, 18 cm wide, and 16 cm deep; it was made of foam boards and covered with blue contact paper. A foam-board flap adhered to the box's top left edge and was 15.5 cm wide, 16 cm deep, and 1 cm thick. The lower portion of the flap was covered with red contact paper and decorated with yellow dots. Its upper portion consisted of either three yellow, triangular projections (5 cm on each edge) decorated with red strips, or a red half circle outlined with light green tape and decorated with dark green stars; the bottom of the half circle flap was 19.5 cm wide and its back was attached to two up-side-down triangle projections that could rest on top of the yellow projections of the jagged flap.

The box was placed over on a small wooden base which was mounted 0.5 cm above the apparatus floor on four small rubber wheels. The base moved along a slit 104 cm wide and 2 cm

deep in the apparatus floor, located 28.5 cm from the left wall and 35 cm from the back wall. Two metal plates anchored to the bottom of the base protruded through the slit in the apparatus floor and were attached beneath the floor to the top of a belt loop. At the start of each trial, the box was positioned at the left end of the slit. When the motorized system that drove the belt loop was activated, the top of the belt moved clockwise, carrying the box to the right at a constant speed of about 50 cm/s. After the box traveled for 75 cm (its leading edge was then 123 cm from the left wall), its metal plates hit a reverse-switch under the apparatus floor; this caused the top of the belt to now move counterclockwise, so that the box was carried back to its starting position. The box then stopped until the motorized system was activated again. During the experiment, an experimenter activated the motorized system by pressing a button on a control panel located under the apparatus floor. The box's movement back and forth across the apparatus was accompanied by noise from the motorized system.

During the experiment, a wall partition filled the left end of the apparatus to hide a window 55.5 cm high and 54 cm wide in the left wall. The left wall partition was made of foam board, was covered with the same grey granite-patterned contact paper as the back of the apparatus, and consisted of four joined surfaces: a front surface, which was attached to the front wall with Velcro and stood parallel to the back wall, two side surfaces, which stood perpendicular to the front wall of the apparatus and one of which was attached to the left wall with Velcro, and a bottom surface, which connected the other three surfaces and was stabilized in position by weights on the apparatus floor. The left wall partition was 58 cm high, 12.5 cm wide, and 25 cm deep.

Another wall partition filled the right end of the apparatus and was fastened in place with Velcro and stabilized with weights. The right wall partition was made of wood, was covered with

the same grey granite-patterned contact paper as the back wall of the apparatus, and consisted of two joined surfaces: a side surface, which stood perpendicular to and abutted the back wall of the apparatus; and a front surface, which stood parallel to the back wall, 13 cm from the front edge of the apparatus. The side surface was 73.5 cm high and 65 cm deep. The front surface was also 73.5 cm high, and could be folded so that its width (and hence the location of the side surface) varied across events. In Experiment 1, the front surface of the wall partition was 21 cm wide, so that the side surface now stood 143 cm from the left wall, 20 cm to the right of the point where the box reversed direction.

The large screen used during the familiarization trials was 51.5 cm high, 41.5 cm wide, and 0.5 cm thick; it was made of foam board, covered with green contact paper, and supported at the back by a metal base. During the familiarization trials, the screen stood parallel to and 15.5 cm from the front edge of the apparatus, and abutted the left wall of the apparatus. The screen hid the starting position of the box's trajectory as it moved back and forth across the apparatus. It also hid the left side window and some portion of the left wall partition. Behind the large screen, there was a small screen that was used in the test event. This screen was made of foam board, was 51 cm wide, 29 cm high, and 0.5 cm thick, was covered with a white contact paper decorated with pastel dots, and was attached to a wooden rod that protruded through a small hole at the bottom of the left wall partition in the apparatus. The right end of the rod was anchored to the apparatus floor with Velcro and the left end was held by an experimenter behind the wall. During the familiarization trials, the experimenter held the screen upright behind the large familiarization screen. During the test trial, the experimenter rotated the rod to raise or lower the screen. In the change test event, a secondary experimenter reached in through the window in the left wall of the apparatus when the small screen was raised and surreptitiously placed or removed

the half-circle flap on top of the jagged flap. When the small screen was lowered, the box appeared to have changed the appearance of its part behind the screen. In the no-change test event, the box remained the same when the screen was lowered.

The infants were tested in a brightly lit test room, and two 40-W fluorescent light bulbs attached to the front and back walls of the apparatus provided additional light. Two wooden frames, each 192 cm high, 63.5 cm wide, and covered with gray cloth, stood at an angle on either side of the apparatus; these frames served to isolate the infants from the test room and to hide the observers sitting behind them. A camera on the wall behind the infant and a camera underneath the apparatus floor projected images of the events and infant onto a TV screen in a different part of the test room; a supervisor monitored the events to confirm that they followed the prescribed scripts. Test sessions were also recorded and checked offline for accuracy.

Events

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

Familiarization event

At the beginning of the event, the box was at the left end of the slit and occluded by the large familiarization screen. Half infants saw the box with the yellow jagged flap, and half saw the box with the red semi-circle flap. In each event cycle, after a 1-s pause, the experimenter pressed the button on the control panel (1 s), out of the infants' sight. The box then moved out from behind the large screen, traveled a short distance, spontaneously reversed direction without hitting the wall partition, and returned to its starting place behind the large screen (4 s). Each

event cycle lasted about 6 seconds; cycles were repeated until the trial ended. When a computer signaled the end of the trial, the supervisor lowered the curtain in front of the apparatus.

Test events

Change event. The large familiarization screen was removed and the small test screen lay flat on the apparatus floor; the box that the infants had seen in familiarization trials stood behind the small screen for a 1-second pre-trial. Next, the screen was raised to occlude the box (2 s) and then the secondary experimenter surreptitiously reached behind the screen and either placed the half-circle flap on top of the jagged flap or removed it (2 s). When the screen was lowered (2 s), the infants could see that the flap of the box appeared to have changed appearance (2 s). This event cycle lasted about 8 seconds and was repeated until the trial ended.

No-change event. The no-change event was identical to the change event except that the flap of the box remained the same through the trial. The secondary experimenter again reached into the apparatus, so that any noises in the no-change test event was similar to the noises in the change test event.

Procedure

At the start of the experiment, the infant sat on a parent's lap in front of the apparatus, facing the center of the large familiarization screen; the infant's head was approximately 60 cm from the screen. Parents were instructed not to interact with their infant during the experiment; they were also asked to close their eyes during the test trial.

The infant's looking behavior was monitored by two observers who watched the infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers could not see the events from their viewpoints and they did not know which of the test events was presented. Each observer held a button box linked to a computer and pressed the button

when the infant attended to the events. The looking times recorded by the primary observer were used to determine when a trial had ended.

The infants first saw the familiarization event for four trials. Each trial ended when the infant either (1) looked away for 2 consecutive seconds after having looked at the event for at least 6 cumulative seconds, or (2) looked for 60 cumulative seconds without looking away for 2 consecutive seconds.

Next, the infants received a single test trial; half the infants saw the change event and the other half saw the no-change event. The test trial ended when the infant (1) looked away for 1 consecutive second after having looked for at least 13 cumulative seconds, or (2) looked for 45 cumulative seconds without looking away for 1 consecutive seconds. The 13-s minimum value corresponded to approximately the second time when the screen was lowered to reveal the box. This value helped ensure that the infant had sufficient opportunity to notice the change in the flap of the box in the change event.

To assess interobserver agreement, the test trial was divided into 100-ms intervals, and the computer determined in each interval whether the two observers agreed on whether the infant was or was not looking at the event. Percent agreement was calculated by dividing the number of intervals in which the observers agreed by the total number of intervals in the trial. Agreement was measured for all 16 infants and averaged 89% per trial per infant. Preliminary analysis of the infants' looking times during the test trial revealed no significant interaction between event and sex, $F(1, 8) = 0.46$; or between event and flap appearance, $F(1, 8) = 1.79$, $p = 0.22$; the data were therefore collapsed across sex and flap appearance in subsequent analyses.

Results

Familiarization trials

The infants' looking times during the four familiarization trials were averaged and analyzed by means of a one-way ANOVA with test event (change and no-change) as a between-subjects factor. The main effect of event was not significant, $F(1, 14) = 1.82$, $p = 0.20$, indicating that the infants who saw the change and no-change test events did not differ reliably in their mean looking times at the familiarization event (change event: $M = 46.6$ s, $SD = 7.8$; no-change event: $M = 39.3$ s, $SD = 13.0$).

Test trial

The infants' looking times during the test trial (see Fig. 6) were analyzed in the same manner as the familiarization trials. The main effect of event was significant, $F(1, 14) = 9.04$, $p < 0.01$, indicating that the infants who saw the change event ($M = 34.5$ s, $SD = 9.7$) looked reliably longer than those who saw the no-change event ($M = 22.3$ s, $SD = 6.1$). Using infants' mean looking times in the familiarization trials as a covariate, we examined whether infants who saw the change test event would still look significantly longer than those in the no-change test event. The result of this ANCOVA was consistent with the result of ANOVA: the main effect of the event was significant, $F(1, 13) = 6.06$, $p < 0.03$. A Wilcoxon rank-sum test also confirmed this result, $W = 91$, $p < 0.02$.

Discussion

In Experiment 1, 5-month-old infants who saw the change test event looked reliably longer than those who saw the no-change event, suggesting that infants were surprised to see the self-propelled box change the appearance of its flap or tail. This result extends previous findings that young infants detect a violation when the appearance of a whole self-propelled object

changes while out of view, and provides evidence that young infants are sensitive to appearance changes in a self-propelled object's part.

These results indicate that young infants understand that a self-propelled object's internal energy cannot enable it to produce an appearance change in either its whole body or its parts. How about other changes? Previous research has found that young infants believe that an internal source of energy enables a self-propelled object to change its location when out of sight. Do infants believe that an internal source of energy enables a self-propelled object to change the location of a part? We conducted Experiment 2 to investigate this question.

Experiment 2

In Experiment 2, we aimed to answer whether 5-month-old infants believe that a self-propelled object can change a part's location. As mentioned earlier, location changes refer to changes in which a part moves to a different side of the object. We speculated that such changes, unlike location changes of a whole object, might seem surprising to infants even for a self-propelled box. If infants interpret a location change in an object's part as indicating that a part has become disconnected from its initial location on the object and has 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., 1995). 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 one of a series of experiments, Slaughter and Heron (2004) found

that 12-month-old infants are sensitive to the location changes of objects' parts. In this experiment, Slaughter and Heron habituated 12-month-old infants to a set of pictures of brightly colored three-dimensional geometric shapes which were called "geobodies". Each of these typical shapes consisted of a large cylindrical red 'torso' with two cylindrical blue 'legs', two cylindrical green 'arms', and a square yellow 'head'. Across these typical shapes, the torso and the head of the shape stayed fixed, but the arms and legs were oriented at different angles from the torso. After habituation, the infants were shown three pictures of scrambled geobodies: the arms and legs of these geobodies were moved to different locations on the torso or the head. These changes were consistent with the definition of location changes in the present research because the parts of the geobodies were disconnected from their original locations and reconnected at new locations on different sides of the figures. Slaughter and Heron found that the 12-month-old infants dishabituated to these scrambled geobodies, suggesting that they were sensitive to the location changes of these geobodies' parts.

In the experiment reviewed above, however, it was not clear how infants construed the pictures of the geobodies—whether they viewed the geobodies as self-propelled or not. In Experiment 2, we aimed to test directly whether infants believe that a self-propelled object's internal energy does not enable it to change the locations of its parts. Using a red box with two rectangular yellow flaps (see Fig. 4 C-D), we tested 5-month-old infants with the same procedure as that of Experiment 1. 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 event; in the change test event, the flap on the right side moved to a new location—a short distance below the flap on the left side. For the other infants, the reverse was true. We expected that the infants who saw the self-propelled box alter the location of its part would be surprised and thus would look reliably longer than the

infants who saw the no-change event.

Method

Participants

Participants were 14 healthy term infants, 7 male and 7 female, ranging in age from 4 months, 10 days to 6 months, 10 days ($M = 5$ months, 4 day). Another 3 infants were tested but eliminated, 1 because of his fussiness, 2 because of their inattentiveness in the familiarization trials (the mean looking times of the four familiarization trials was less than 18 seconds).

Apparatus

The apparatus used in Experiment 2 was identical to that in Experiment 1 except that a new foam-board box was used. The box was 21 cm wide, 12 cm high, and 17.5 cm deep, and was covered with red contact paper. A foam-board flap, 10 cm wide, 17.5 cm deep and 1 cm thick, was covered with yellow contact paper at the box's top left side. The edges of the flap were covered with 1cm red tape. Another identical flap protruded from the top right side of the box and it was connected to a third identical flap hidden inside of the box. The flap on the right side could be pushed inside the box, causing a third flap to protrude from the left side of the box, 5 cm below the flap on the top left. The flaps could roughly be described as "arms". The top front edge of the box was decorated with 5 large pom-poms, 3 red and 2 yellow; a red pompom was also attached to each corner at the bottom of the box.

Events and Procedure

The events and procedure used in Experiment 2 were identical to those in Experiment 1. In the familiarization trials, half the infants saw the two flaps on the opposite sides of the box at the same height, and half saw both flaps on the left side of the box at different levels. In the test trial, half the infants saw the change event in which one flap changed location on the box, and

half saw the no-change event in which both flaps remained at the same locations on the box (see Fig. 7).

Interobserver agreement was measured for all 14 infants and averaged 87% per trial per infant. Preliminary analysis of the infants' looking times during the test trial revealed no significant interaction between event and sex, $F(1, 7) = 0.42$, or between event and flap location, $F(1, 7) < 1.39$, $p = 0.28$; the data were therefore collapsed across sex and flap location in subsequent analyses.

Results

Familiarization trials

The infants' looking times during the four familiarization trials were averaged and analyzed as in Experiment 1. The main effect of event was not significant, $F < 1$, indicating that the infants who saw the change and no-change test events did not differ reliably in their mean looking times at the familiarization event (change event: $M = 40.9$ s, $SD = 8.8$; no-change event: $M = 36.8$ s, $SD = 15.9$).

Test trial

The infants' looking times during the test trial (see Fig. 6) were analyzed as in Experiment 1. The main effect of the event was significant, $F(1, 12) = 8.27$, $p < 0.02$. The results revealed that the infants who saw the change event ($M = 38.0$ s, $SD = 11.2$) looked reliably longer than those who saw the no-change event ($M = 23.3$ s, $SD = 7.5$). Using infants' mean looking times in the familiarization trials as a covariate, we examined whether the infants in the change test event would still look significantly longer than those in the no-change test event. The result of this ANCOVA was consistent with the result of ANOVA: the main effect of the event was

significant, $F(1, 11) = 7.07$, $p < 0.025$. A Wilcoxon rank-sum test also confirmed this result, $W = 36$, $p < 0.05$.

Discussion

The results of Experiment 2 indicated that the infants who saw the change event looked reliably longer than those who saw the no-change event. Once again, 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 2 extend the results of Slaughter and Heron (2004) mentioned earlier in at least two ways. First, they suggest that, when shown a simple self-propelled object with two parts, infants as young as 5 months of age detect when one of the parts changes location and view it as unexpected. 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 2 whether the two parts were initially on the same side or on the opposite sides of the box. These results suggest that the infants realized that no application of internal energy could allow a self-propelled object to disconnect a part (a cohesion violation) and reconnect it elsewhere (a boundedness violation).

The results in Experiments 1 and 2 suggested that 5-month-old infants believe that a self-propelled object cannot produce appearance and location changes in its parts. Would 5-month-old infants view any kind of changes in a self-propelled object's part as impossible or surprising? In Experiments 3 and 4, we asked whether 5-month-old infants would also view position and orientation changes in a self-propelled object's part as impossible.

Experiment 3

Experiments 1 and 2 suggested that 5-month-old infants believe that no application of internal energy enables a self-propelled object to change the appearance or the location of a part. Could this mean that infants believe that a self-propelled object cannot produce any change in its parts? Or could it be that infants simply find events involving changes more interesting than events involving no change? We suspected that these might not be the case for two reasons. First, infants may have some experience of position changes in a self-propelled object's parts in daily life. For example, infants watch people around them lift and lower their shoulders, eyelids, eyebrows, lower jaw, and so on. Second, young infants may have limited understanding of how connections or joints are constructed or of how far they can stretch or shift in any direction. In the same series of experiments, Slaughter and Heron (2004) habituated infants aged 12 to 18 months to photos of typical human bodies (e.g., arms and legs located at the correct positions, but oriented in different directions). After habituation, the infants were shown photos of scrambled human bodies of which arms and legs were at different positions on the same sides of the human torso (e.g., arms at the legs' positions, or legs at the arms' positions). These were the position changes defined in the present research. They found that at 12 months of age, the infants were not sensitive to the position changes of the arms and legs on the scrambled human bodies; it was not until 15 to 18 months of age that the infants dishabituated to the scrambled bodies. However, they found that the 12-month-old infants did dishabituate to the photos in which the arms and legs underwent location changes on the human torso (e.g., two arms on the same side of the body). These results suggest that (1) 12-month-old infants may not have a clear understanding about joints and articulations between parts and bodies, and (2) therefore they are more likely to detect a location change than a position change; (3) whereas older infants with

more experience may possess more precise knowledge of joints and articulations than younger infants and may therefore detect both location and position changes.

A recent research by Southgate and her collaborators (2008) also suggested that 6- to 8-month-old infants have limited understanding of how elbows work. Southgate et al. first habituated 6- to 8-month-old infants to a video-taped event in which a human arm moved an obstructing box out of the way and then reached out and retrieved a ball. In the test phase, the infants saw one event (possible/less efficient event) in which the arm pushed a second box out of its obstructing position and then reached to retrieve the ball, and another event (impossible/more efficient event) in which the arm snaked around the second box to reach the ball. They found that the infants were not surprised to see the arm twist its elbow in an impossible way to reach for its goal in the most efficient way, but were surprised to see the arm retrieve the ball in the less efficient but possible way. Their results imply that young infants may view the arm's action in the more efficient event as physically possible because they have only a shallow understanding of how elbows work.

Based on these previous results, we speculated that for 5-month-old infants a self-propelled object with an internal source of energy may be able to change its parts' positions. With a very abstract understanding of how the internal energy and joints of self-propelled objects work, young infants may believe that it is possible for a self-propelled box to use its internal energy to alter its parts' positions up or down on the same side of the object (e.g., perhaps in the same way that a man can move his shoulders, or his eyebrows, up or down).

Experiment 3 aimed to examine infants' responses to events in which the parts of a self-propelled box changed positions when it 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. Using an experimental design similar to that of Experiments 1 and 2, we tested 5-month-old infants in Experiment 3 with a new red box. The box was decorated with two blue stripes at the bottom and sported a yellow rectangular flap on either side, parallel to the apparatus floor (see Fig. 4 E-F). Both flaps could change their positions to a different height on the same side of the box. All the infants first received four trials of the familiarization event in which the flaps were either even with the top of the box or just above the blue stripes at the bottom on the box. In the two-arm-change test event, both flaps changed positions when out of sight (i. e., from top to bottom or from bottom to top). However, one possibility was that the infants might view this change as indicating that the box had flipped over when hidden. Therefore, Experiment 3 included another change test event: a one-arm-change test event in which only one of the flaps changed to a different position when out of the view; the flip-over of the box could not result in a one-arm position change of the box. In the no-change test event, the box's flaps remained at the same positions throughout the event (see Fig. 8). We predicted that the infants would not be surprised to see the self-propelled box to change the positions of its parts, and hence the infants who saw the change events would look about as long as the infants who saw the no-change event.

Method

Participants

Participants were 27 healthy term infants, 14 male and 13 female, ranging in age from 4 months, 20 days to 6 months, 7days ($M = 5$ months, 11 days). Another infant was tested but eliminated because of fussiness. 9 infants were randomly assigned to view the two-arm-change event (4 male and 4 female; $M = 5$ months, 6 days), 9 infants watched the one-arm-change event

(4 male and 5 female; $\underline{M}$ = 5 months, 13 days), and 9 infants watched the no-change event (5 male and 4 female; $\underline{M}$ = 5 months, 12 days).

Apparatus

The apparatus in Experiment 3 was the same as in Experiments 1 and 2 except that a new wooden box was used. This box was 22 cm wide, 20 cm high, and 17 cm deep, and covered with red contact paper. A stripe of blue felt 4 cm wide was glued to the front bottom of the box to hide the gap between the box and the apparatus floor. The two foam-board flaps of the box were 10.5 cm wide, 17 cm deep, and 1cm thick, and covered with yellow contact paper. In the two-arm- and no-change test events, the two flaps were connected by a metal strip that rested on two wooden supports at the back of the box. The two flaps lined up with the top by resting on the support located 3 cm below the top of the box. The two flaps could be moved down by resting on the support positioned 5 cm above the bottom of the box. To ensure that the infants noticed the bottom of the box, the box was decorated with a 1.5 cm wide blue tape around its body, 4 cm above the bottom. Four pom-poms were glued to the top and bottom corners of the box and another four were glued to the front and back points of the flaps. In the one-arm-change test event, the box had two disconnected flaps. The two separate flaps looked the same as the connected ones, but could be moved up or down separately.

Events and procedure

The events and the procedure of Experiment 3 were identical to those in Experiments 1 and 2. In the two-arm-change test event, 4 infants saw the positions of the two flaps changed from the top to the bottom, and 5 infants saw their positions changed from the bottom to the top. In the one-arm-change test event, 4 infants saw the position of one arm changed from the top to the bottom, and 5 infants saw one arm changed from the bottom to the top.

Interobserver agreement was measured for 26 of the 27 infants (only one observer was present for one of the infants) and averaged 91% per trial per infant. Preliminary analysis of the infants' looking times during the test trial revealed no significant interaction among event, sex, and flap position, $F(2, 15) = 1.62$, $p = 0.23$; the data were therefore collapsed across sex and flap position in subsequent analyses.

Results

Familiarization trials

The infants' looking times during the four familiarization trials were averaged and analyzed by the means of a one way ANOVA with event (two-arm-change, one-arm-change, and no-change) as a between-subjects factor. The main effect of event was not significant, $F(2, 24) < 1$, indicating that the infants who saw the three test events did not differ reliably in their mean looking times at the familiarization event (two-arm-change event: $M = 32.7$ s, $SD = 15.3$; one-arm-change event: $M = 42.0$ s, $SD = 13.1$; no-change event: $M = 42.4$ s, $SD = 15.4$).

Test trial

The infants' looking times during the test trial (see Fig. 9) were analyzed in the same manner as the familiarization trials. The main effect of event was not significant, $F(2, 24) < 1$, suggesting that the infants looked about equally at the three test events (two-arm-change event: $M = 23.2$ s, $SD = 11.3$; one-arm-change event: $M = 22.1$ s, $SD = 9.2$; no-change event: $M = 23.8$ s, $SD = 10.5$). We compared the infants' looking times in the two change test events to the infants' looking times at the no-change test event by means of a Wilcoxon rank-sum test, and the result confirmed the results of the ANOVA, $W = 129.5$, $p = 0.87$.

Further results

For the first time, we found that 5-month-old infants looked about equally at both the change and no-change events they were shown, suggesting that they might believe that a self-propelled object can use its internal energy to change the positions of its parts. However, there was an alternative interpretation of the results. That is, perhaps, the position change was not as salient as the other two changes—appearance and location changes—and thus the infants in Experiment 3 did not detect the position changes of the self-propelled box's flaps. To examine whether this alternative interpretation was correct, we conducted a control condition (inert condition) which was identical to the experimental condition (self-propelled condition) except that the front surface of the right wall partition was now 41 cm wide, so that the side surface stood 123 cm from the left wall of the apparatus, at the point where the box reversed direction in the self-propelled condition (see Fig. 8). In this way, the arm of the box appeared to hit the side surface of the wall partition and to “bounce back” (in actuality, the reverse-switch under the apparatus caused the box to reverse direction). Based on previous research, we reasoned that the infants should view the box in the control condition as inert because its reversal could be explained by hitting the wall.

If the position changes of the box's flaps were not salient enough for the infants in the self-propelled condition to detect, the infants in the inert condition would behave in the same way and look about equally at the test events. But if the infants in the self-propelled condition looked about equally at the test events because they believed that the self-propelled box could use its internal energy to change the positions of its flaps, the infants in the inert condition might have different looking patterns in the test events. That is, the infants in the inert condition who

saw the change test events might look reliably longer than those who saw the no-change test event, because an inert box without internal energy could not change the position of its flaps.

Twenty-seven healthy term infants, 15 male and 12 female, (ranging in age from 4 months, 20 days to 6 months, 6 days; $\underline{M}$ = 5 months, 9 days) were tested in the inert condition. Another 4 infants were tested but eliminated, 2 because they were distracted by their dresses during the experiment, and 2 because their looking times were beyond 2.5 standard deviations from the mean of their condition. 9 infants were randomly assigned to view the two-arm-change event (6 male and 3 female; $\underline{M}$ = 5 months, 15 days), 9 infants saw the one-arm-change event (4 male and 5 female, $\underline{M}$ = 5 months, 2 days), and 9 infants saw the no-change event (5 male and 4 female; $\underline{M}$ = 5 months, 9 days).

Interobserver agreement was measured for all 27 infants and averaged 90% per trail per infant. Preliminary analysis of the infants' looking times during the familiarization and test trials revealed no significant interactions between event and either sex or flap position, $\underline{F}$ s (2, 15) $\leq$ 1.15, p = 0.35; the data were therefore collapsed across sex and flap position in subsequent analyses.

The infants' looking times were analyzed as Experiment 3 (see Fig. 9). The infants in the different test event conditions looked about equally at the familiarization event (two-arm-change event: $\underline{M}$ = 42.1 s, $\underline{SD}$ = 13.1; one-arm-change event: $\underline{M}$ = 44.0 s, $\underline{SD}$ = 14.0; no-change event: $\underline{M}$ = 40.0 s, $\underline{SD}$ = 15.0), $\underline{F}$ < 1. However, the infants differed significantly in their looking times at the test events, $\underline{F}$ (2, 24) = 5.57, p < 0.015. Both the infants in the two-arm-change test event ($\underline{M}$ = 34.8 s, $\underline{SD}$ = 11.1), $\underline{F}$ (1, 24) = 8.14, p < 0.01, and the infants in the one-arm-change test event ($\underline{M}$ = 35.2 s, $\underline{SD}$ = 14.3), $\underline{F}$ (1, 24) = 8.57, p < 0.01, looked reliably longer than the infants

in the no-change test event ($\underline{M} = 20.3$ s, $\underline{SD} = 4.6$). A Wilcoxon rank-sum test confirmed this result, $\underline{W} = 75$, $p < 0.01$.

In a final analysis, we compared the infants' looking times in the self-propelled and inert conditions by using a two-way ANOVA with condition (self-propelled and inert) and event (two-arm-change, one-arm-change, and no-change) as between-subjects factors. The results indicated that the infants in both conditions looked about equally at the familiarization event, $\underline{F}(2, 48) < 1$, but differed reliability in their looking times at the test events, $\underline{F}(2, 48) = 3.38$, $p < 0.05$.

Discussion

The results of Experiment 3 indicated that in the inert condition, the infants who saw the change events looked reliably longer than those who saw the no-change event, whereas in the self-propelled condition, the infants looked about equally at the three test events. The infants were thus surprised when the inert but not the self-propelled box changed the positions of its flaps up or down. These results and those of Experiments 1 and 2 suggest that infants as young as 5 months of age can not only detect changes in a self-propelled object's parts, but also understand that an application of internal energy can produce certain kinds of changes, like position changes, but not other kinds of changes, such as appearance and location changes.

In the self-propelled condition, the infants who saw the two-arm-change test event looked about equally as those who saw the one-arm-change test event, suggesting that the infants in the two-arm-change test event did not simply think that the self-propelled box had flipped over when hidden. When only one arm changed its position, the infants still believed that it was possible for the self-propelled box to effect the change. Together, these results indicated that infants as young as 5 months of age believe that a self-propelled but not an inert object can change the position of a part.

Experiment 4

Using an experimental design similar to that of Experiment 3, in Experiment 4 we asked whether 5-month-old infants believe that a self-propelled but not an inert box with internal energy can change the orientation of its parts. The infants were assigned to an inert or a self-propelled condition and were shown events involving the box that from Experiment 1, with a single, jagged flap on the left. The flap could either lie parallel to the floor or rest against the top of the box (See Fig. 4 G-H). The experiment by Slaughter and Heron (2004) mentioned earlier reported that 12-month-old infants did not discriminate the pictures of the human bodies and geobodies whose arms and legs were oriented at different angles from the torso. This result implies that young infants may believe that a self-propelled object can use its internal energy to alter the orientation of its parts. Therefore, we predicted that the infants in Experiment 4 would believe that the self-propelled could alter its flap's orientation up or down, and hence the infants who saw the change and no-changes event would look about equally during the test trial. To make sure that infants did not simply fail to detect the orientation change in the change event, we also conducted an inert condition. We expected that, in the inert condition the infants who saw the change event should look reliably longer than those who saw the no-change event.

Method

Participants

Participants were 28 healthy term infants, 13 male and 15 female, ranging in age from 4 months, 9 days to 6 months, 6 days ($M = 5$ months, 8days). Another 5 infants were tested but eliminated, 1 because of fussiness, 1 because he was distracted by the rotating screen, and 3 because their looking times were beyond 2.5 SD from the mean of their own condition. Half the

infants were randomly assigned to the inert condition (7 male and 7 female; $\underline{M}$ = 5 months, 9 days), and half to the self-propelled condition (6 male and 8 female, $\underline{M}$ = 5 months, 6 days).

Apparatus, Events, and Procedure

The apparatus, events, and procedure used in Experiment 4 were identical to those in Experiment 3, except that the box used was the one from Experiment 1 (see Fig. 10). In the change event, the flap of the box alternatively lay parallel to the apparatus floor or against the top of the box. In the no-change event, the flap of the box lay parallel to the apparatus floor throughout the test trial.

Interobserver agreement was measured for 25 of the 28 infants (only one observer was present for three other infants) and averaged 88% per trial per infant. Preliminary analysis of the infants' looking times during the test trials revealed no significant interaction among condition, event, and sex, $\underline{F}$ (1, 20) = 1.61, p = 0.22; the data were therefore collapsed across sex in subsequent analyses.

Results

Familiarization trials

The infants' looking times during the familiarization trials were averaged and analyzed by means of a two-way ANOVA with condition (inert and self-propelled) and event (change and no-change) as between-subjects factors. The main effects of condition, $\underline{F}$ (1, 24) = 0.02, and event, $\underline{F}$ (1, 24) = 0.78, and the interaction between condition and event, $\underline{F}$ (1, 24) = 3.53, p = 0.07, were not significant. These results suggested that the infants in four experimental groups did not differ reliably in their mean looking times during the familiarization trials (inert/change group: $\underline{M}$ = 40.5 s, $\underline{SD}$ = 12.5; inert/no-change group: $\underline{M}$ = 36.7 s, $\underline{SD}$ = 10.4; self-propelled/change group: $\underline{M}$ = 33.9 s, $\underline{SD}$ = 8.3; self-propelled/no-change group: $\underline{M}$ = 44.3 s, $\underline{SD}$ = 8.0).

Test trial

The infants' looking times during the test trial (see Fig. 11) were analyzed in the same manner as the familiarization trials. The main effects of condition, $F(1, 24) = 3.78$, $p = 0.06$, and event $F(1, 24) = 1.03$, $p = 0.32$, were not significant, but the interaction of condition and event was, $F(1, 24) = 7.36$, $p < 0.02$. Planned comparisons revealed that the infants in the inert condition looked reliably longer if shown the change ($M = 31.1$ s, $SD = 10.1$) than the no-change ($M = 17.9$ s, $SD = 2.6$) event, $F(1, 24) = 10.85$, $p < 0.005$, whereas the infants in the self-propelled condition looked about equally at the two events (change event: $M = 20.5$ s, $SD = 7.8$; no-change event: $M = 22.7$ s, $SD = 7.5$), $F(1, 28) = 0.29$. Using infants' meaning looking times in the familiarization trials as a covariate, we examined whether there was still a significant interaction of condition and event in the test trial. The result of this ANCOVA was consistent with the result of ANOVA: the interaction of condition and event was, $F(1, 23) = 8.56$, $p = 0.008$. Wilcoxon rank-sum tests confirmed the results (inert: $W = 71$, $p < 0.02$; self-propelled: $W = 57$, $p = 0.62$).

Further results: Experiment 4A

With the same experimental procedure, another 32 infants (ranging in age from 4 months, 12 days to 6 months, 12 days, $M = 5$ months, 17 days; half male) were tested with a new box with two flaps on the top of its two sides (see Fig. 4 I-J). Another 2 infants were tested but eliminated, 1 because of fussiness, 1 because of observer difficulties. Half the infants were in the self-propelled condition, and half in the inert condition. Within each condition, half the infants received the change test trial, and half received the no-change test trial.

The new box was made of foam board, was 12.5 cm high, 19 cm wide, and 16.5 cm deep, and was covered with blue contact paper. The top of the box was covered with red contact paper

and decorated with yellow dots. Two 13 cm long, 1cm wide, and 16.5 cm deep foam-board flaps were attached to the left and right top sides of the box. When upright, the flaps rested against each other to form an 8.5 cm high triangle. Small magnets were attached to the top edges of the flaps to ensure that they did not move. The flaps were covered with red contact paper and decorated with yellow dots. Yellow pom-poms were attached to the front corners of the flaps to cover the joints between the two flaps and the box. In the change event, the two flaps alternately rested against each other on the top of the box or opened and lay parallel to the apparatus floor; in the no-change event, the two flaps rested against each other on the top of the box throughout the trial (see Fig. 12).

The infants' looking times were analyzed as in Experiment 4 (see Fig. 13). The infants in the inert and self-propelled conditions looked about equally at the familiarization trials, $F < 1$ (inert/change group: $M = 33.4$ s, $SD = 21.2$; inert/no-change group: $M = 36.1$ s, $SD = 11.9$; self-propelled/change group: $M = 38.8$ s, $SD = 10.8$; self-propelled/no-change group: $M = 40.4$ s, $SD = 12.4$). In test, there was a significant interaction of condition and event, $F(1, 28) = 5.70$, $p < 0.025$, and a significant main effect of event, $F(1, 28) = 4.26$, $p < 0.05$, but no significant main effect of condition, $F(1, 28) < 1$. Planned comparisons revealed that in the inert condition the infants who saw the change event ($M = 39.0$ s, $SD = 8.6$) looked reliably longer than those who saw the no-change event ($M = 24.2$ s, $SD = 10.0$), $F(1, 28) = 9.97$, $p < 0.005$, whereas in the self-propelled condition the infants looked about equally at the two test events (change event: $M = 34.2$ s, $SD = 9.7$; no-change event: $M = 35.4$ s, $SD = 9.1$), $F < 1$. Wilcoxon rank-sum tests confirmed these results (inert: $W = 82$, $p < 0.02$, self-propelled: $W = 64$, $p = 0.88$).

Discussion

The results of both Experiments 4 and 4A were as predicted: 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 both test events. Together, these results suggested that 5-month-old infants realize that a self-propelled object can use its internal energy to alter the orientation of its parts. Infants as young as 5 months of age were surprised when the parts of an inert but not a self-propelled object surreptitiously changed orientation.

General Discussion

Taken together, the results of Experiment 1 to 4 suggest that infants as young as 5 months of age recognize that a self-propelled object cannot change the appearance (Experiment 1) and location (Experiment 2) of its parts, but can change the position (Experiment 3) and orientation (Experiment 4) of its parts. Furthermore, they understand that, unlike a self-propelled object, an inert object does not possess internal energy and thus cannot produce position and orientation changes in its parts.

The present results, together with previous findings, suggest 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 (e.g., Luo et al., 2009; Wu et al., 2006, 2010), or to change a part's position (Experiment 3) or a part's orientation (Experiment 4). 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 (e.g., Luo, et al., 2009), changing a part's appearance (Experiment 1) or a part's location (Experiment 2). 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; but their concept of self-propelled object and rudimentary understanding of internal energy still help them to make rich inferences about objects' actions in new contexts. Therefore, infants who endow a self-propelled box with internal energy may not understand exactly how this internal energy works or where it comes from, but they understand that the box can use its energy to produce some kinds of changes—position and orientation changes—in its parts, but cannot use its energy to produce other changes—appearance and location changes—in its parts.

The present and previous research primarily focused on infants' understanding of self-propelled objects in the physical-reasoning domain. But this gives rise to an interesting question: whether infants construe those self-propelled objects merely as physical entities. As we know, many self-propelled objects are not only physical entities, but also agents and biological beings. Humans, for instance, are not only self-propelled objects: they are also agents that can pursue goals and animals that are composed of biological matter and can undergo biological

transformations such as growth. Is it possible that the infants in the present and previous research viewed the self-propelled boxes, balls, cylinders, and columns which were shown to them not only as self-propelled objects, but also as agents and animals? We will discuss this issue more in the following chapters. But we suggest that the infants in the present research viewed the box which spontaneously reversed its motion trajectory merely as a self-propelled object. As we mentioned in Chapter 1, infants only view an object as self-propelled when provided clear evidence that the object possesses internal energy. For the same reason, we believe that infants need extra evidence to construe a self-propelled object as an agent or an animal. Therefore, the infants in the present research only construed the box as self-propelled.

A related question is whether the infants in the present research view the four kinds of changes as merely physical. As orientation change, for example, can be merely physical because it can simply be explained in terms of the self-propelled box using its internal energy to exert a force on its parts to alter their directions. But the appearance changes of a self-propelled object cannot only be explained by an application of internal energy. In fact, many appearance changes are not purely physical processes, but involve biological processes. Would infants believe that some appearance changes are acceptable when a self-propelled object is an animal? We would return to discuss this question in Chapter 4.

CHAPTER 3

CAN AN AGENT BE INERT? 14-MONTH-OLD INFANTS' REASONING ABOUT AGENCY WITHOUT MOTION CUES

In Chapter 2, we discussed how infants predict the behaviors of physical entities, self-propelled and inert objects, in physical events in terms of a notion of internal energy. In real life, infants encounter not only physical events, but also psychological events. Psychological events involve objects which pursue their goals or detect their environment (e.g., Leslie, 1994). These objects are ontological entities in the psychological-reasoning domain, referred to as agents. Research on infants' psychological reasoning has indicated that young infants interpret and predict agents' behaviors in accordance with their mental states, such as dispositions, preferences, goals, and so on (e.g., Bellagamba & Tomasello, 1999; Carpenter et al., 1998; Gergely et al., 1995; Luo & Baillargeon, 2005; Meltzoff, 1995; Rizzolatti & Craighero, 2004; Song & Baillargeon, 2007; Woodward, 1998; Woodward & Guajardo, 2002). One fundamental question of interest in the psychological-reasoning domain is what those "agents" are—what entities can be agents.

3.1. What objects can be agents?

Generally speaking, two opposing approaches provide different answers. On one hand, an experience-based approach suggests that infants' understanding of agents' actions is acquired through their own experience as they begin to perform goal-directed actions (e.g., Meltzoff, 2005; Rizzolatti & Craighero, 2004; Woodward, 2005; Woodward, Sommerville, & Guajardo, 2001; Tomasello, 1999; Tomasello, Carpenter, Call, Behen, & Moll, 2005). Though disagreeing on what mechanism infants use to form their knowledge of intentional actions, the advocates of this

approach agree that infants initially view only humans or human-like objects as agents and gradually extend the range of agents to non-human objects.

On the other hand, a system-based approach states that infants' understanding of psychological events stems from an innate, abstract, specialized computational reasoning system. According to this approach, infants attribute goals or preferences to any entity that they identify as an agent, whether human or non-human (e.g., Baron-Cohen, 1994; Gergely & Csibra, 2003; Johnson, 2000; Leslie, 1994, 1995; Luo & Baillargeon, 2005; Premack, 1990). Proponents of this approach differ in their opinions on the nature of the systems of psychological reasoning and based on what information infants recognize an agent, but they all agree that from early on infants construe both human and non-human objects as agents.

Increasing experimental evidence supports the system-based view: young infants construe both human and non-human as agents, including self-propelled boxes, computer-animated shapes and animals, novel blobs, puppets, and so on (e.g., Csibra, 2008; Gergely, et al., 1995; Luo & Baillargeon, 2005; Saxe et al., 2007; Schlottmann & Ray, 2010; Shimizu & Johnson, 2004; Surian et al., 2006).

3.2. What information do infants use to identify an agent?

A question that the proponents of the system-based approach need to answer is how infants identify an entity—and especially a novel non-human entity—as an agent in the psychological-reasoning domain. An earlier proposal suggests that self-propulsion is a sufficient cue for infants to identify a novel object as an agent (e.g., Premack, 1990; Premack & Premack, 1995, 1997). According to this proposal, young infants would construe all self-propelled objects as agents. An object's self-propelled behavior triggers the identification of an intentional agent and the interpretation of its behavior in terms of internal states, such as dispositions, preferences,

and goals. However, this proposal was not supported by recent empirical evidence, which indicates that self-propulsion is not a sufficient cue for infants to construe an object as an agent (e.g., Csibra, 2008; Johnson et al., 2007; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Shimizu & Johnson, 2004).

3.2.1. Is self-propulsion sufficient?

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 the experimental paradigm of Woodward (1998). The infants were habituated to an event in which a self-propelled object, an oval-shaped “blob”, approached and stopped against object A as opposed to object B at the back of an apparatus floor. During the test trials, the objects’ 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, suggesting that they viewed the blob as a self-propelled object—since it initiated its motion in plain sight—but not as an agent. Therefore, the blob’s self-propulsion was not sufficient evidence for infants to construe the blob as an agent: the blob could be an agent pursuing the goal of approaching object A—but it could also be a self-propelled object moving on a fixed path that happened to intersect with object A.

Support for this interpretation came 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 objects 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). All these results suggest that infants are sensitive to different types of evidence for internal states. A blob that beeps contingently in a conversation with an experimenter gives evidence of internal states because it appears to be detecting and responding to the utterances of the experimenter. Similarly, a blob that first rotates toward and then approaches one of the two objects on the apparatus floor gives evidence of internal states because it appears to be adjusting its behavior so as to achieve a particular goal, namely, contacting its preferred toy.

Recent work by Csibra (2008) points to yet another type of evidence for internal states: choosing different means to achieve the same goal across trials. The 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, et al., 1995). Kamewari et al. habituated 6.5-month-old infants to a videotaped event in which an agent moved around an obstacle to reach a

target. The agent was either a human, a human-like robot, or a self-propelled box. In test, the obstacle was removed, and the agent 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 by using a computer-animated self-propelled box, and suggested that, because the box followed the same fixed path in every habituation trial, the infants were not certain whether it was an agent; it was clearly self-propelled, but there was perhaps insufficient evidence that its actions were intentional. To test this idea, Csibra 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 either the right or the left end of the obstacle randomly across the 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 a box a goal of reaching the target, and they expected the box 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, these research findings suggest that infants do not view self-propulsion as sufficient evidence of possessing internal states. Other behavioral cues, such as taking turns in a conversation with a partner, modifying one's behavior in order to achieve a goal, and selecting different means at different times to achieve the same goal, may be used by infants to determine whether a novel object is an agent.

3.2.2. Is self-propulsion necessary?

Another related question is whether infants believe that an agent must be self-propelled. In another word, is self-propulsion necessary for infants to view a novel object as an agent? There is not much direct research evidence to answer this question. However, previous research indicates that self-propulsion may not be necessary for infants to view an action as goal-directed. In one of Woodward's (1998) experiments, she examined whether 5-month-old infants attribute a goal to a human arm or a non-human object. The infants were randomly assigned to a hand or a rod condition. In the hand condition, the infants were habituated to an event in which a hand reached and grasped object A but not object B on an apparatus floor. After the habituation trials, the objects' positions were switched. Then, the infants saw two test events in alternation. In the new-goal event, the hand reached for and grasped the new object (object B) at the old position. In old-goal event, the hand reached for and grasped the old object (object A) at the new position. The infants in the rod condition saw the same events except that the hand was replaced by a rod. Woodward found that the infants in the hand condition looked reliably longer at the new- than at the old-goal event, whereas the infants in the rod condition looked about equally at the two test events. The results suggested that the infants viewed the hand as an agent, attributed a goal to the hand, and expected the hand to maintain its goal and thus to continue to reach for the old object. In contrast, the infants did not view the rod as an agent, did not attribute a goal to the rod, and thus not expect the rod to reach for the old object.

The negative results of the rod condition might have arisen because the infants were confused about whether the rod was a mechanical tool or a non-human agent. In the rod condition, the rod protruded from the right side of the apparatus and its right end was occluded. Thus, it was ambiguous whether the rod was manipulated by someone else behind the apparatus.

With its long handle, the rod could be a mechanical device held by an unseen agent. Young infants seem to have limited understanding of how tools work. There were at least three possible difficulties for young infants to interpret the rod's action as goal-directed. First, infants may not know how a tool can be manipulated by others. Second, infants may not be clear how tools can be guided by an agent's goal-directed actions. Last, it may be hard for young infants to infer the existence of an unseen agent. These difficulties might cause the negative results of the rod condition in Woodward's experiment.

This interpretation was tested and confirmed by Hofer, Hauf, & Aschersleben (2005). Hofer, Hauf, and Aschersleben habituated 9- and 12-month-old infants to an event in which a mechanical claw grasped and transported one of two toys to the back of the apparatus. Then, the locations of the two toys were reversed. In test, the infants saw two test events in which the claw grasped and transported either the old toy at the new location (old-goal event) or the new toy at the old location (new-goal event) to the back of the apparatus. They found that 12- but not 9-month-old infants looked reliably longer at the new- than at the old-goal event in the test trials. These results suggest that (1) 12- but not 9-month-old infants attributed a goal to the claw after the habituation trials, (2) expected the claw to maintain its goal when the locations of the toys were reversed, and (3) thus surprised to see the claw grasp the new toy in the new-goal event. Hofer et al. suggested that the 12-month-old infants viewed the claw as a tool which was operated by an invisible human agent. The 12-month-olds had a more mature understanding of tool-use than the 9-month-olds so that they could view a tool's action as goal-directed and attribute a goal to an unseen human agent. In the following experiment, Hofer et al. familiarized the 9-month-old infants to the mechanical claw and showed them an event in which an experimenter operated the claw just before the habituation and test trials. They found that, like

the 12-month-olds in the previous experiment, the 9-month-olds now looked reliably longer at the new- than at the old-goal test event, suggesting that they viewed the claw's action as goal-directed. More evidence shows that infants may construe an object as a tool and the object's action as goal-directed without obvious evidence of self-propulsion (e.g., a poking paper tube protruding through the side of an apparatus in the study by Biro and Leslie (2007), and a flying ball emerging from occluded area in the study by Csibra et al. (1999).

3.3. Inert agent

In the present research, we aimed to directly answer the question of whether self-propulsion is necessary for infants to identify an object as an agent. If not, then it leads to a strong condition: for infants, an agent can be inert. For adults, the concept of inert agent is not unfamiliar. Exemplars of inert agents are available in both fictional literatures and real world: for example, think about the Mirror, Mirror on the wall in Snow White who always responds accurately when asked for the name of the fairest woman in the kingdom. As adults, we would construe it as an inert agent because even though it cannot initiate its own motion, it is capable of responding intentionally to fulfill its goals. For the same reason, we construe objects, like the evil ring in the Lord of Rings and the mystery diary in Harry Potter, as inert agents. In real life, the super computer, "Deep Blue", which defeated the world chess champion, could also be thought of as an inert agent since it decided its own steps to win the game. Sadly, patients who have locked-in syndromes can be viewed as inert agents too because they cannot move any of their muscles but their brains still selectively respond to external stimuli.

3.4. The present research

We hypothesized that when an inert object appears to act intentionally, infants construe it as an agent. We conducted two experiments to examine whether 14-month-old infants would

view an inert object as an agent. Inspired by the work of Johnson and her colleagues (Johnson et al., 2007; Shimizu & Johnson, 2004), we showed infants a box which never moved on its own, but responded to an experimenter's utterances by modulated beeps as though it was conversing with the experimenter. As we discussed earlier, the box's contingent beeping responses provided clear evidence of internal states, and thus the infants would construe it as an agent and attribute a goal or a preference to it. In Experiment 5, adopting the experimental paradigm of Woodward (1998), we examined whether 14-month-old infants would attribute a preference to the beeping box. If self-propulsion is not necessary for infants to construe an object as an agent, we predict that 14-month-old infants would view the beeping box as an agent and attribute a preference to it. However, if infants believe that all agents must be self-propelled or the box used its internal energy to move some internal parts to beep, then the infants in Experiment 5 might construe the box as self-propelled even though it never moved. Therefore, in Experiment 6 we examined whether 14-month-old infants viewed the beeping box as an inert or a self-propelled object. We reasoned that evidence that infants viewed the beeping box both as an agent (Experiment 5) and as an inert object (Experiment 6) would indicate that infants believe that agents can be inert.

Experiment 5

The research by Johnson and her colleagues (Johnson et al., 2007; Shimizu & Johnson, 2004) suggested that contingent beeping responses to a human agent provided clear evidence for having internal states. In Experiment 5, we asked whether 14-month-old infants would construe an inert box as an agent after watching it respond contingently to an experimenter's utterances by beeping sounds, and would then attribute a preference to it when it appeared to favor one toy over another. We randomly assigned the infants into a two- or a one-toy condition. In the two-toy condition, the infants first received an orientation trial in which they saw a box resting stationary

on an apparatus floor. Next, in a conversation trial, the infants watched the box responding contingently to an experimenter's utterances in modulated sounds as though it conversed with the experimenter. The infants then received two familiarization trials in which the box faced two identical covers; a gloved hand lifted each cover in turn to reveal two different toys (a ball and a block), and the box beeped when toy A but not toy B was revealed (as though it preferred toy A over toy B). Before the test trials, the locations of the two toys were reversed in the display event. During the test trials, the box either beeped to toy A at the new location (old-object event), or beeped to toy B at the old location (new-object event) (see Fig. 14). If the infants construed the box as an agent, and attributed a preference to the box when it repeatedly beeped to toy A but not to toy B, then they should be surprised when the box beeped to the new toy (toy B), and hence they should therefore look reliably longer at the new- than at the old-object event.

In the one-toy condition, the infants saw events similar to those in the two-toy condition except that there was only one toy underneath the left cover in the familiarization trials. As a control, this condition was used to exclude an alternative explanation of the positive results in the two-toy condition, which was that the infants might simply form an association between toy A and the box's beeps. If the infants in the two-toy condition simply associated the beeping sound with toy A, the infants in the one-toy condition should form the same association and thus be surprised to see the box beep to the new toy—toy B—in the new-object event, for they would expect the box to beep when the old toy—toy A—was revealed. Therefore, the infants in the one-toy condition, as the infants in the two-toy condition should look reliably longer at the new- than at the old-object event. However, if the infants in the two-toy condition attributed a preference for toy A to the beeping box after they saw the familiarization event, the infants in the one-toy might have a different looking pattern during test. In the one-toy condition, the infants

would not attribute a preference to the box because there was only one toy in the familiarization event, the infants had no information about which toy, A or B, the box would prefer when both were visible. In other words, they had no way to predict whether the box would still beep to the old toy—toy A—or the new toy—toy B—in the test events. If this was the case, we predicted that the infants in the one-toy condition would look about equally at both test events.

Method

Participants

Participants were 32 healthy, full term infants, 17 males and 15 females ($M = 14$ months, 9 days; range = 13 months, 17 days to 14 months, 25 days). Another 9 infants were tested but eliminated, 7 because they were fussy and did not complete the experiment, 1 because he was obsessed with the ball during the experiment, and 1 because her looking times were beyond 2.5 SD from the mean of her condition. Half the infants were randomly assigned to the two-toy condition ($M = 14$ months, 7 days), and half to the one-toy condition ($M = 14$ months, 10 days). Within each condition, half of the infants saw the box beep to the ball in the familiarization events, and half saw the box beep to the block.

Apparatus

The apparatus consisted of a wooden display booth (125 cm high $\times$ 164 cm wide $\times$ 78 cm deep). The infant sat on a parent's lap and faced an opening (46 $\times$ 157.5 cm) in the front of the apparatus; between trials, a muslin-covered frame (56.5 $\times$ 163 cm) was lowered in front of this opening. A wooden wall partition, covered with the grey granite-patterned contact paper, filled the right end of the apparatus (all descriptions are from the infant's perspective). It consisted of two joined surfaces: a side surface (73.5 $\times$ 65 cm), which stood perpendicular to and abutted the back wall of the apparatus; and a front surface (73.5 $\times$ 71 cm), which stood parallel to the back wall. A

side window (52×55 cm) on the left wall was covered with a white solid curtain in the orientation and conversation events, and with a white fringed curtain in the familiarization and test events. The box consisted of a cardboard box ($10.5 \times 17 \times 10$ cm) covered with red contact paper and decorated with white parallel stripes. The box rested on a slit 104 cm wide and 2 cm deep in the apparatus floor. Two metal sticks, each 25 cm long, were attached to the bottom of the box and protruded through the slit in the apparatus floor. The back of the box could be opened and two small speakers (SRS-p7 stereo speaker system from Sony Inc) were placed inside.

In the familiarization, display, and test events, a red wooden ball and a green plastic block were placed on the apparatus floor. The ball was 6 cm in diameter and decorated with silver stars. The green block was a cube, 5 cm a side, with small holes and light brown lines scattered on its surface. The red ball and the green block were placed under two identical covers, each 10 cm wide, high, and deep, and covered with brown wood-patterned contact paper; each cover had a wooden knob centered on its top.

The infants were tested in a brightly lit test room, and two 40-W fluorescent light bulbs attached to the front and back walls of the apparatus provided additional light. A camera on the wall behind the infant and a camera underneath the apparatus floor projected images of the events and the infant onto a TV screen in a different part of the test room; a supervisor monitored the events to confirm that experimenters followed the prescribed scripts. Test sessions were recorded and checked offline for accuracy.

Events

Orientation event

The infants first received an orientation event in which the box remained stationary on the apparatus floor throughout the trial. The box was positioned 35 cm from the left side wall and 35 cm from the front of the apparatus.

Conversation event

After the orientation event, the infants in both conditions received a conversation trial. The box rested at the same location as before. An experimenter first opened the solid curtain in the left window and placed her bare hands on the edge of the window (1 s); next, she looked at the box (1 s) and started talking to it. The box responded contingently to her utterances with modulated beeps. After the conversation, which lasted about 47 s, the experimenter closed the curtain and left the apparatus (1 s). Following this 50-second pretrial, the box remained stationary and silent until the trial ended.

Familiarization event

Two-toy condition. The box rested at the same location as before and was centered in the middle of two covers. The two covers were placed 10 cm in front of the box. The covers stood 25 cm apart, 19 cm away from the front edge of the apparatus. A gloved hand entered the apparatus through the fringed curtain in the left window. The hand reached for and grasped the knob of the left cover (2 s), and then lifted the cover 7.5 cm above the apparatus floor to reveal toy A (1 s) and paused for 2 seconds. During the pause, the box beeped in a short modulated sound. After these beeps, the hand lowered the cover over toy A (1 s). The hand then reached for and grasped the knob of the right cover (2 s). The hand lifted the cover to reveal toy B (1 s), and paused for 2 seconds. During the pause, the box remained silent. Then, the hand lowered the

cover over toy B (1 s). The hand returned to the left cover again and the whole event cycle was repeated until the trial ended.

One-toy condition. The event was similar to the event in the two-toy condition except that toy B was absent and the box beeped when the toy A under the left cover was revealed.

Display event

The display event served to introduce the infants to the new positions of the two toys.

Two-toy condition. The red box was removed from the apparatus and the two covers stood at their original locations. The locations of toy A and toy B were reversed so that toy A was now under the right cover and toy B under the left cover. The gloved hand entered the apparatus through the fringed curtain on the left window and reached for and grasped the knob of the left cover (2 s). The hand lifted the cover 7.5 cm above the apparatus floor (1 s) to reveal toy B and paused for 2 seconds. The hand then lowered the cover behind toy B (1 s). Next, the hand reached and grasped the knob of the right cover (2 s). The hand lifted the cover 7.5 cm above the apparatus floor (1 s) to reveal toy A and paused for 2 seconds. The hand then lowered the cover behind toy A (1 s) and withdrew out of the apparatus (2 s). After this 14-second pretrial, the toys stood still in front of the covers until the main trial ended.

One-toy condition. The display event was the same as in the two-toy condition.

Test events

New-object event. The new-object event was similar to the familiarization event except that the two toys' positions were reversed and the box beeped when toy B was revealed.

Old-object event. The old-object event was similar to the new-object event except that the box beeped when toy A was revealed.

Procedure

During the experiment, the infant sat on a parent's lap in front of the apparatus, facing the center of the box on the apparatus; the infant's head was approximately 51 cm from the front of the apparatus. Parents were instructed not to interact with their infants during the experiment; they were also asked to close their eyes during the test trials.

Orientation event. The infants in the two conditions (two-toy or one-toy) received one trial of the orientation event. The trial ended when the infants either (1) looked away from the event for 2 consecutive seconds after having looked at it for at least 15 cumulative seconds, or (2) looked for 30 cumulative seconds without looking away for 2 consecutive seconds.

Conversation event. The infants in the two conditions received one trial of the conversation event. The main trial ended when the infants either (1) looked away from the event for 2 consecutive seconds after having looked at it for at least 5 cumulative seconds, or (2) looked for 30 cumulative seconds without looking away for 2 consecutive seconds.

Familiarization event. The infants received two trials of the familiarization event appropriate for their condition (two-toy or one-toy). Each trial ended when the infants either (1) looked away from the event for 2 consecutive seconds after having looked at it for at least 24 cumulative seconds, or (2) looked for 90 cumulative seconds without looking away for 2 consecutive seconds. The 24-s minimum value corresponded to approximately two event cycles and was chosen to ensure that the infant had sufficient opportunity to notice which toy the box beeped to.

Display event. The infants in both conditions received one trial of the display event. The main trial ended when the infants either (1) looked away from the event for 2 consecutive

seconds after having looked at it for at least 15 cumulative seconds, or (2) looked for 30 cumulative seconds without looking away for 2 consecutive seconds.

Test events. The infants in both conditions received four test trials. The new- and the old-object event were shown in alternation. The order of the events was counterbalanced across infants. Each test trial ended when the infants (1) looked away from the event for 1 consecutive second after having looked for at least 24 cumulative seconds, or (2) looked for 60 cumulative seconds without looking away for 1 consecutive second.

Two observers monitored each infant's looking behavior through peepholes in cloth-covered frames (192 × 63.5 cm) on either side of the apparatus. The interobserver agreement during the four test trials was measured for 30 of the 32 infants (2 infants were observed by only one observer) and averaged 93% per trial per infant.

Preliminary analyses of the infants' looking times during the test trials revealed no significant interactions of condition and event with sex, order, or toy, all $F_s < 1$; the data were therefore collapsed across sex, order, and toy in subsequent analyses.

Results

Pretest events

The infants' looking times during the pretest events (the orientation, conversation, familiarization, and display events) were analyzed by means four of one-way ANOVAs with condition (two-toy or one-toy) as a between-subjects factor. No significant main effect of condition was found in any of the analyses, all $F_s < 1$, indicating that the infants in the two conditions did not differ reliably in their mean looking times at the orientation (two-toy: $M = 20.6$ s, $SD = 4.0$; one-toy: $M = 20.5$ s, $SD = 4.3$), conversation (two-toy: $M = 17.4$ s, $SD = 5.8$; one-toy: $M = 17.7$ s, $SD = 7.1$), familiarization (two-toy: $M = 71.3$ s, $SD = 16.3$; one-toy: $M =$

67.7 s, $\underline{SD} = 14.8$), and display (two-toy: $\underline{M} = 23.4$ s, $\underline{SD} = 5.8$; one-toy: $\underline{M} = 23.9$ s, $\underline{SD} = 5.8$) events.

Test events

The infants' looking times at the test events were analyzed by means of two-way ANOVA with condition (two-toy or one-toy) as a between-subjects factor and test event (new-object or old-object) as a within-subjects factor (see Fig. 15). The main effects of condition, $\underline{F} (1, 30) = 1.10$, $\underline{p} = 0.30$, and test event, $\underline{F} (1, 30) = 3.78$, $\underline{p} = 0.06$, were not significant. The interaction of condition and test event was significant, $\underline{F} (1, 30) = 4.71$, $\underline{p} < 0.05$. Planned comparisons revealed that infants in the two-toy condition looked reliably longer at the new- ($\underline{M} = 46.7$ s, $\underline{SD} = 9.1$) than at the old-object ($\underline{M} = 39.9$ s, $\underline{SD} = 7.3$) test event, $\underline{F} (1, 30) = 4.23$, $\underline{p} < 0.05$, whereas the infants in the one-toy condition looked about equally at the new- ($\underline{M} = 40.1$ s, $\underline{SD} = 9.6$) and the old-object test events ($\underline{M} = 40.5$ s, $\underline{SD} = 10.9$), $\underline{F} < 1$.

Examination of the individual infants' mean looking times during the test trials indicated that, whereas 12 of the 16 infants in the two-toy condition looked longer at the new- than at the old-object test event, Wilcoxon signed-ranks $\underline{T} = 19$, $\underline{p} < 0.01$, only 6 of the 16 infants in the one-toy condition did so, $\underline{T} = 65$, $\underline{p} > 0.50$.

Discussion

As predicted, the infants in the two-toy condition looked significantly longer at the new- than at the old-object event, whereas those in the one-toy condition looked about equally at the two test events. These results suggested that the infants in the two-toy condition (1) interpreted the box's beeps as revealing a particular disposition, a preference for toy A over toy B; (2) expected the box to maintain this preference when the toys' locations were reversed; and hence

(3) were surprised in the new-object event when the box did not maintain its preference, but beeped to the other toy.

These results of Experiment 5 suggested that the infants construed the box as an agent and attributed a preference to it. However, a remaining question was whether the infants in Experiment 5 viewed the box as inert or self-propelled. On one hand, the infants might have viewed the box as inert because there was no unambiguous evidence that the box was capable of self-generated motion. As we discussed in the previous chapters, infants hold a default assumption that an object is inert unless proven otherwise. Therefore, the infants might have viewed the box as inert due to the lack of self-propulsion cues.

On the other hand, the infants might have viewed the box as self-propelled for two reasons. First, infants might have an expectation that all agents are self-propelled. In this view, the infants in Experiment 5 would have viewed the box as self-propelled even though it never moved because it was an agent. Second, infants might believe that a beeping box must move its internal parts to produce beeps; in this view, the infants in Experiment 5 would have viewed the box as self-propelled because it beeped. In order to answer whether the infants in Experiment 5 viewed the box as inert or self-propelled, we conducted Experiment 6.

Experiment 6

To investigate whether the infants viewed the box in Experiment 5 as inert or self-propelled, we took advantage of a recent research finding by Luo et al. (2009). They found that 6.5-month-old infants believe that a self-propelled but not an inert box can remain suspended when released in midair. In their experiment, 6.5-month-olds were assigned to a self-propelled or an inert condition. In the inert condition, the infants were familiarized with an event in which a box emerged from behind the right edge of a large screen and traveled a short distance until it hit

the right wall of the apparatus and reversed direction, as though bouncing back, to return behind the screen. In the self-propelled condition, the infants saw a similar familiarization event except that the right wall of the apparatus was placed farther to the right, so that the box appeared to reverse direction spontaneously without hitting the wall. As discussed earlier, infants assume that an object is inert until proven otherwise. Thus, the infants should view the box as inert when its reversal could be explained by hitting the wall, and as self-propelled when it could not.

In the test phase, half of the infants received a no-support event in which the box was held by a gloved hand, and then released to remain suspended in midair; the other half of the infants received a partial-support event in which 1/3 or 1/6 of the bottom of the box was supported by a platform when it was released by the hand. Luo et al. (2009) found that the infants in the inert condition looked reliably longer at the no- and partial-support events than did the infants in the self-propelled condition. These results suggested that the infants in the inert condition (1) viewed the box as an inert object because there was no clear evidence that it was able to move on its own, (2) expected the box to fall when released in midair with partial or no support from the platform, and hence (3) were surprised to see the box remain stable. In contrast, the infants in the self-propelled condition (1) considered the box as a self-propelled object because it reversed direction spontaneously, (2) endowed the box with an internal source of energy which enabled it to remain suspended when released in midair with partial or no support from the platform, and hence (3) were not surprised to see the box remain stable.

Recently, Yuan and Baillargeon (2008) have found that infants as young as 2.5 months of age also understand that a self-propelled but not an inert cylinder can float in midair without support. Other research on infants' physical reasoning also found that young infants were not surprised to see self-propelled objects, such as self-propelled rods and toys, floating in midair

(e.g., Kellman & Spelke, 1983; Leslie & Keeble, 1987). With imprecise understanding of how internal energy works, infants expect self-propelled but not inert objects to float in midair when released. Even in real life, it is not hard to observe that birds, bees, and some other insects appear to float in midair. When spaceships float in space, as adults, we are not surprised by that either.

Therefore, if the infants in Experiment 5 viewed the box as an inert agent, they might expect it to fall when released, and be surprised if it remained suspended in midair. Conversely, if the infants in Experiment 5 believed that the box was a self-propelled agent, they should not be surprised to see the box remain suspended in midair. In Experiment 6, 14-month-old infants were randomly assigned into an inert or a self-propelled condition. In the inert condition, the infants received the same orientation, conversation, and familiarization events as in the two-toy condition of Experiment 5. In this way, the infants should view the box as an agent just as those in Experiment 5 did. Next, the infants saw a display event in which a gloved hand held the box in midair. The display event served to introduce the infants to the test situation. In the test event, the box was released and remained suspended in midair. The infants in the self-propelled condition saw identical events except that the box moved back and forth on the apparatus floor in the orientation event (see Fig. 16).

Based on previous research, we predicted that the infants in the self-propelled condition would construe the box as a self-propelled agent and understand that it could remain suspended when released in midair. Therefore, they should not be surprised to see the box float in midair without support. In the inert condition, if the infants also construed the box as a self-propelled agent, they should look at the test event about as long as the infants in the self-propelled condition. However, if the infants in the inert condition construed the box as an inert agent (since they received no unambiguous evidence that the box was self-propelled), then the infants should

be surprised to see the box remain suspended in midair when released. Therefore, the infants in the inert condition should look reliably longer at the test event than those in the self-propelled condition.

Method

Participants

Participants were 16 healthy, full term infants, 8 males and 8 females ($M = 14$ months, 13 days; range = 14 months, 0 days to 14 months, 24 days). Another 4 infants were tested but eliminated, 3 because they were fussy and active, and 2 because they looked for the maximum looking time allowed (60 s). Half the infants were randomly assigned to the inert condition ($M = 14$ months, 12 days), and half to the self-propelled condition ($M = 14$ months, 13 days). Within each condition, half the infants saw the box beep to the ball, and half saw the box beep to the block in the familiarization events.

Apparatus, Events, and Procedure

The apparatus was identical to that in Experiment 5. The infants in the inert condition received the same orientation, conversation, and familiarization events as those in the two-toy condition of Experiment 5. The infants in the self-propelled condition saw similar events except that, in the orientation event, the box traveled a short distance (22.5 cm) to the right (2 s), returned to its starting position (2 s), and continued moving back and forth in this way until the trial ended. Infants in both conditions then saw a static display event in which a gloved hand held the box stationary in midair. In the display event, a red box, identical to the one used in Experiment 5 and in the orientation, conversation, and familiarization events of Experiment 6, was attached to a wooden stick ($5 \times 33 \times 0.5$ cm) which was connected to a wooden stand hidden behind a trap door in the back wall. In the display and the test trials, the box was 15 cm above

the floor, 50.5 cm from the left wall and 30 cm away from the back wall of the apparatus. The display trial ended when the infants either (1) looked away from the event for 1 consecutive second after having looked at it for at least 3 cumulative seconds, or (2) looked for 20 cumulative seconds without looking away for 1 consecutive second.

Finally, all infants received one test trial in which the gloved hand held the box in midair for 1 second, and then released the box and withdrew (1 s) about 10 cm away from the box (2 s). The hand then gasped the box again (1 s) to start a new event cycle. This 5-s event cycle was repeated until the trial ended. This occurred when the infants (1) looked away from the event for 0.5 consecutive second after having looked for at least 5 cumulative seconds, or (2) looked for 50 cumulative seconds without looking away for 0.5 consecutive seconds.

The interobserver agreement in the test trial was measured for all 16 infants and averaged 97% per infant. No reliable differences were found between the looking times of the infants in the two conditions during the orientation (inert condition: $\underline{M}$ = 22.5 s, $\underline{SD}$ = 5.3; self-propelled condition: $\underline{M}$ = 25.6 s, $\underline{SD}$ = 4.8), $\underline{F}$ (1, 14) = 1.48, p = 0.24, conversation (inert condition: $\underline{M}$ = 18.0 s, $\underline{SD}$ = 5.2; self-propelled condition: $\underline{M}$ = 19.1 s, $\underline{SD}$ = 6.5), familiarization (inert condition: $\underline{M}$ = 72.6 s, $\underline{SD}$ = 12.7; self-propelled condition: $\underline{M}$ = 75.0 s, $\underline{SD}$ = 12.6), and display (inert condition: $\underline{M}$ = 12.9 s, $\underline{SD}$ = 5.2; self-propelled condition: $\underline{M}$ = 11.6 s, $\underline{SD}$ = 5.8) trials, all $\underline{F}$ s < 1. Preliminary analysis of the infants' looking times during the test trial revealed no significant interaction between condition and sex, $\underline{F}$ < 1; the data were therefore collapsed across sex in subsequent analyses.

Results

The infants' looking times at the test event were analyzed by means of one-way ANOVA with condition (inert or self-propelled) as a between-subjects factor (see Fig.17). The main effect

of condition, $F(1, 14) = 6.71$, $p < .025$ was significant, indicating that the infants in the inert condition ($M = 30.1$ s, $SD = 6.7$) looked reliably longer at the test event than did the infants in the self-propelled condition ($M = 20.6$ s, $SD = 7.8$). A Wilcoxon rank-sum test confirmed this result, $W_s = 46$, $p < 0.025$.

Further Results

To provide converging evidence for the results of Experiment 6, an additional group of infants was tested with the same apparatus and events except that they did not receive the two familiarization trials (see Fig. 18). The infants saw that the box conversed with a human agent in the conversation event which should provide them sufficient evidence to identify it as an agent. The experimental procedure was the same as that of Experiment 6 except that the test trial ended when the infants (1) looked away from the event for 1 second after having looked for at least 5 cumulative seconds, or (2) looked for 60 consecutive seconds without looking away for 1 second. The infants received fewer trials in this experiment and thus they tended to be more attentive during the test trial than those in Experiment 6. Therefore, longer minimum and maximum looking times were used here. The participants were 16 healthy, full term infants, 8 males and 8 females ($M = 13$ months, 22 days; range = 13 months, 1 day to 14 months, 16 days). Another 4 infants were tested but eliminated, 3 because of fussiness, and 1 because her looking times were beyond 2.5 SD from the mean of her condition. Half the infants were randomly assigned to the inert condition ($M = 13$ months, 25 days), and half to the self-propelled condition ($M = 13$ months, 18 days).

The interobserver agreement in the test trial was measured for all 16 infants and averaged 94% per trial per infant. The infants' looking times at the orientation, conversation, display and test events were analyzed as in Experiment 6 (see Fig. 19). No reliable differences were found

between the looking times of the infants in the two conditions during the conversation (inert condition: $\underline{M} = 21.3$ s, $\underline{SD} = 5.3$; self-propelled condition: $\underline{M} = 15.9$ s, $\underline{SD} = 7.5$), $\underline{F} (1, 14) = 2.74$, $\underline{p} = 0.12$, and display trials (inert condition: $\underline{M} = 14.1$ s, $\underline{SD} = 4.4$; self-propelled condition: $\underline{M} = 17.0$ s, $\underline{SD} = 3.8$), $\underline{F} (1, 14) = 1.98$, $\underline{p} = 0.18$. Unlike the infants in Experiment 6, the infants in the self-propelled condition ($\underline{M} = 26.7$ s, $\underline{SD} = 4.7$) looked reliably longer at the orientation event than did the infants in the inert condition ($\underline{M} = 19.2$ s, $\underline{SD} = 4.8$), $\underline{F} (1, 14) = 10.24$, $\underline{p} < 0.01$. This discrepancy might be due to the fact that younger infants were tested here and they tended to look longer at the orientation event when the box moved by itself on the apparatus floor. However, this discrepancy did not make a difference in the results of the test event. The one-way ANCOVA analysis with the infants' looking times at the orientation event revealed that the infants in the inert condition looked reliably longer at the test event than did the infants in the self-propelled condition, $\underline{F} (1, 13) = 6.31$, $\underline{p} < 0.03$. This was consistent with the results of one-way ANOVA of the infants' looking times in the test event. Preliminary analysis of the infants' looking times during the test trial revealed no significant interaction between condition and sex, $\underline{F} (1, 12) < 1$; the data were therefore collapsed across sex in subsequent analyses. The results showed that the infants in the inert condition ($\underline{M} = 46.9$ s, $\underline{SD} = 15.2$) looked significant longer than the infants in the self-propelled condition ($\underline{M} = 25.3$ s, $\underline{SD} = 11.9$), $\underline{F} (1, 14) = 10.0$, $\underline{p} < 0.01$. A Wilcoxon rank-sum test confirmed this result, $\underline{W}_s = 44.5$, $\underline{p} < 0.02$.

Discussion

In Experiment 6, the infants in the inert and the self-propelled conditions looked about equally at the orientation, conversation, familiarization, and display events. However, the infants in the inert condition looked reliably longer at the test event than did those in the self-propelled condition. These results suggested that the infants in the inert condition (1) viewed the box as an

inert agent, (2) expected the box to fall when released in midair, and hence (3) were surprised when the box remained stable in midair instead. In contrast, the infants in the self-propelled condition (1) considered the box as a self-propelled agent, (2) endowed the box with an internal energy which enabled it to remain suspended when released in midair, and hence (3) were not surprised to see the box remain stable. These results once again indicated that without clear evidence that a novel object can move on its own, infants tend to view the object as inert even if it is an agent.

General Discussion

Taken together, the results of Experiments 5 and 6 provide evidence that 14-month-olds believe that an agent can be inert. 14-month-old infants would attribute a preference to a stationary box if it provides evidence of possessing internal states, such as conversing with a human agent (Experiment 5). At the same time, infants expect this box to fall as opposed to remain suspended when released in midair (Experiment 6). Together with previous research (e.g., Biro & Leslie, 2007; Csibra, 2008; Csibra, et al., 1999; Gergely et al., 1995; Gergely & Csibra, 1997, 2003; Johnson et al., 2007; Kawemari et al., 2005; Shimizu & Johnson, 2004), the present results suggest that self-propulsion is neither sufficient nor necessary for infants to identify an object as an agent. Moreover, the present research provides additional evidence to support the system-based view of infants' psychological-reasoning domain: the 14-month-old infants viewed an inert non-human object as an agent and attributed a preference to it.

If self-propulsion is not crucial for infants to identify an agent, what sort of information or behavioral cues do they use to categorize a novel non-human object as an agent? Biro and Leslie (2007) suggested that there are multiple behavior cues, such as self-propelled movement,

variability of actions, equifinal target approaches, and an action-effect, that infants use to identify an agent.

Gergely (2009) proposed that the identification of agents is determined by whether objects' actions are rational: an agent responds to the changes in accordance with the efficiency principle, which suggests that an agent achieves its goal in the most efficient way possible. According to this view, the evidence that infants use to identify an agent is whether an object is capable of making rational choice. For example, the infants in the study by Shimizu and Johnson (2004) attributed a goal to the self-propelled blob only when it was shown that it chose its course of action freely and the infants in Biro and Leslie's (2007) work viewed the tube's behavior as goal-directed only when it varied its approaching path in the most effective way.

Another way to answer the question of how infants identify agents is that they use the observable behavioral evidence in accordance with a notion of internal states to categorize an object as an agent. These internal states include motivational states (e.g., dispositions and goals), informational states (e.g., perceptions and inferences), and fictional states (e.g., beliefs and pretences). Based on previous research, it seems that a single behavior cannot be convincing evidence for possessing internal states. An object has to provide evidence that it detects the changes in the environment, suggesting that the object has an informational mental state, and varies its behaviors corresponding to the changes, suggesting that the object has a motivational mental state. For example, the beeping box in the present research and the beeping blob in Johnson et al. (2007) exhibited evidence of possessing internal states by detecting a human agent and her utterance—an information state—and responding contingently to the utterance—a motivational state.

When there was no change in the environment, an object's behavior has to show different internal states. For example, in the study by Shimizu and Jonhson (2004), the blob first turned toward one of the two toys on the apparatus floor, suggesting that it possessed a motivational state—making a choice between the two different toys; then it moved to contact the toy, exhibiting a second motivational state—approaching the toy. In the studies of Csibra (2008) and Kawemari, et al. (2005), if the box always moved in an unchanged route, though it initiated its own motion, suggesting it was a self-propelled object; infants did not view it as an agent because this single behavior did not provide sufficient evidence that the box had varied mental states.

The present results also help us better understand the conceptual basis of infants' cognitive development. 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 unambiguous evidence that it can act intentionally and thus has mental states. Infants appear to hold separate concepts of self-propelled object and agent: the first is rooted in the causal framework that makes possible their physical reasoning, and the second is rooted in the causal framework that makes possible their psychological reasoning. In another word, self-propelled objects are objects that have internal energy, whereas agents are objects that have internal states. On the one hand, not all self-propelled objects are agents. For example, ceiling fans and moving clouds both appear to move on their own without obvious external force, and therefore infants should view them as self-propelled objects. But none of them would be viewed as agents because they do not provide sufficient evidence of possessing internal states. On the other hand, not all agents are self-propelled. The results of the current research suggest that infants believe that an agent can be inert. Therefore, the results in the present research support the core-concept view about infants'

object categorization: the concepts of self-propelled object and agent are two independent concepts in two separate domains.

Though independent, as we see, there is an overlap between these two concepts. There are objects that are both self-propelled and agentive, like humans and animals. The question is how infants construe objects that are both self-propelled and agents. Since most animals are self-propelled and agents, do infants view all self-propelled agents as animals? If they do, infants should endow animals with internal energy and internal states, and view animals as causal entities in both physical and psychological events.

Previous research suggests that infants are biased to learn about self-propelled agents and associate them with some biological properties, such as faces, fur, and biological motions (Johnson, Slaughter, & Carey, 1998; Pauen & Träuble, 2009; Schlottmann & Ray, 2010). When there is ambiguous evidence of self-propelled motion, infants tend to view an object with a face and furry body as a causal entity which moves on its own and causes another object, like a plastic ball, to move (e.g., Pauen & Träuble, 2009). When there is no clear evidence of internal states, infants tend to view an object with biological features as agents who behave intentionally. For example, Johnson et al. (1998) found that 12-month-old tended to follow the gaze of a novel blob with a face even when the blob did not show any evidence of internal states by beeping and flashing back contingently to the infants' babbles and movements. Infants' sensitivity to biological features of self-propelled agents may imply that infants have additional expectations of this group of objects. Further research is necessary to investigate what those expectations are and whether those expectations are quasi-biological in nature.

CHAPTER 4

CAN AN ANIMAL BE HOLLOW? 7-MONTH-OLDS' EXPECTATIONS ABOUT THE INSIDES OF ANIMALS

When infants identify an object as self-propelled, they endow the self-propelled object with an internal source of energy and expect the object to use its internal energy to initiate its own motion, reverse its motion trajectories, float in midair without support, and so on. A crucial question is whether infants' concept of self-propelled object only contains the property of internal energy, or whether it includes a constellation of additional 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 can undergo biological transformations such as growth and death. Did infants in previous research on physical reasoning view the self-propelled objects they were shown, including balls, cylinders, boxes, and humans, in the same way? Did infants merely construe these self-propelled objects as physical entities, or did they also view them as psychological entities (agents) or as biological entities (animals), or as all of these? Recent research on infant's psychological reasoning, however, has implied that infants do not simply equate self-propelled objects with psychological agents (Baillargeon, et al., 2009; Csibra, 2008; Johnson et al., 2007; Schlottman & Ray, 2010; Shimizu & Johnson, 2004). For infants, an agent must present evidence that it possesses different internal states. Previous results and the results in Chapter 3 suggest that self-propulsion is neither sufficient nor necessary for infants to construe an object as an agent. Infants do not construe a self-propelled object as an agent if its behaviors manifest no evidence of intention. In contrast, infants do construe an inert object as an agent if it provides evidence of multiple internal states.

No research has directly examined whether infants also construe self-propelled objects as animals. The present research aimed to investigate whether young infants construe self-propelled objects as animals. As one might expect, how one answers this question depends on how one characterizes infants' concept of animal. There are at least two possible characterizations which are discussed below.

4.1. Animals as self-propelled agents

One is suggested by Mandler's (2010) proposal that infants distinguish animals from non-animals and their concept of animal is composed of two conceptual primitives: objects "that start motion by themselves" and objects "that interact contingently with other objects from a distance". Thus, according to the first characterization, infants would view animals essentially as self-propelled agents. In this first characterization, the concepts of self-propelled object and agent would each be embedded in a causal framework—the concept of self-propelled object (with its link to internal energy) in the causal framework that makes infants' physical reasoning possible (e.g., Baillargeon, Li, et al., 2006; Baillargeon, Wu, et al., 2009; 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 infants' psychological reasoning possible (e.g., Gergely & Csibra, 2003; Johnson, 2003; Luo & Baillargeon, 2007; Premack, 1990; Scott & Baillargeon, 2009). Therefore, the first characterization is non-biological: an animal is nothing more than a self-propelled agent. According to this view, infants may view an object as an animal if it provides clear evidence of self-propulsion and intention, or either a self-propelled object or an agent with features that have come with experience to be associated with animals, such as faces, fur, and biological behaviors, like drinking and eating.

There is much evidence that infants are biased to attend to animals and rapidly learn about their surface properties, parts, motions, behaviors, and so on through associative learning (Arterberry & Bornstein, 2002; Johnson et al., 1998; Mandler & McDonough, 1996; Pauen & Träuble, 2009; Rakison, 2003; Rakison & Poulin-Dubois, 2001; Schlottman & Ray, 2010; Subrahmanyam et al., 2002). Previous research suggests that young infants attend to perceptual information about animals and can use it to differentiate animals from other self-propelled artifacts. For example, infants can use dynamic cues to distinguish animals from other self-propelled objects. In one study by Arterberry and Bornstein (2002), they found that 6-month-olds could discriminate dynamic point-light displays of animals from those of vehicles. Moreover, they habituated 9-month-olds to the dynamic point-light displays of animals or vehicles and then tested the infants with static images of animals or vehicles. They found that the infants who were habituated to the dynamic point-light displays of animals looked reliably longer at the static images of vehicles than at the images of animals during the test, whereas the infants who saw the point-light displays of vehicles in the habituation looked longer at the animals' images than at the vehicles' images, suggesting that the infants used the dynamic categorical information to distinguish static images of animals from vehicles. Based on these results, Arterberry and Bornstein suggested that at 9 months, infants discriminate animals from vehicles not only at the perceptual level but also at the conceptual level. This may imply that at least infants as young as 9 months of age have associated biological motions with animals.

Infants also use features related to objects' appearance to distinguish animal from other objects. For example, Pauen and Träuble (2009) showed 7-month-old infants three scenes. In the first scene, two separate objects—an unfamiliar animal (with a face and furry body) and a ball—rested at two corners of a small stage. During the second scene, infants saw both objects

connected physically and moving on their own in an irregular path. It was ambiguous whether the animal or the ball was self-propelled and caused the other object to move, because both objects were connected and moved together. The third scene was identical to the first one. During the third scene, the infants showed prolonged looking time at the animal but not at the ball, suggesting that they viewed the novel animal as a self-propelled object, assumed that the animal caused the ball to move in the second scene, and expected the animal to move again in the third scene. However, when either the face was removed or the furry body was replaced by a plastic spiral, the infants did not prefer to look at the animal any more in the third scene. These results suggest that at 7 months infants believe that an object with biological features, like fur and faces, is more likely to be self-propelled than objects that lack these features.

Furthermore, McDonough and Mandler (1998) found that infants discriminate animals from vehicles and understand what kinds of behaviors are appropriate for animals or vehicles. They showed 9- and 11-month-old infants events in which an experimenter demonstrated two animal-appropriate properties (drinking and sleeping) to a replica of a dog (e.g., a dog drinking from a cup) and two vehicle-appropriate properties (riding and keying) to a replica of a car (e.g., a car giving a ride). Then, infants were given exemplars from a typical set of exemplars (a cat, a bird, a truck, and an airplane) and a novel set of exemplars (an ox, an anteater, a shoveler, and a forklift) to imitate the exemplars' action. McDonough and Mandler recorded infants' generalization behavior, that is, whether the infants generalized the properties demonstrated to the exemplars from the appropriate domain or from the inappropriate domain. They found that both 9- and 11-month-old infants imitated the properties with both typical and novel exemplars within the appropriate domain, but rarely applied the properties with the typical and novel exemplars within the inappropriate domain.

4.2. Animals as more than self-propelled agents

A second characterization of animals is that infants possess broad, abstract expectations about animals that go beyond the separate properties of being self-propelled objects and agents. These expectations might be characterized as quasi-biological.

Not much research has been conducted to examine infants' quasi-biological expectations about animals. Previous work on young children's knowledge about animals and other objects suggests that young children distinguish animals from other objects and hold biological expectations about animals. For example, Subrahmanyam et al. (2002) interviewed 4- to 5-year-old children and adults about animals, machines, inert objects, using questions dealing with multiple animal properties, including behavioral properties (e.g., move and talk), biological properties (e.g., brain and breath), and psychological properties (e.g., think and remember). They found that both young children and adults considered machines differently from animals. Although they realized that both machines and animals were capable of moving and possessed some psychological properties, they have disinclined to believe that both kinds of objects were subject to the same causal principles. When asked about animals, such as persons, dogs, and elephants, both children and adults talked about biological features (e.g., muscles, bones, and blood), causes (e.g., wanting to move), and biological notions (e.g., alive, living). When questioned about machines, both groups talked about non-biological materials (e.g., plastic, glass), parts (e.g., wheels, buttons), and mechanical causes (e.g., battery, electricity). Based on these and other results, Subrahmanyam et al. suggested that young children clearly categorize animals and machines differently. Though young infants do not have a content-rich biological theory about animals, their early knowledge of animals is embedded in a set of domain-specific, skeletal causal principles. Gelman (1990, 2000) calls those principles the innards and external

agent principles that lead children to attend to the source of energy and their consequences in different events. She suggests that the kind of stuff that an object is made of is yoked to these innards and external agent principles. Massey and Gelman (1998) asked preschoolers whether a novel object in a photo was able to move itself up and down a hill. They found that the preschoolers answered the questions in accord with the appropriate causal principles and selectively attended to those objects' parts and what kind of stuff they were made of (e.g. an echidna, made of the right stuff, could move up and down the hill because it had feet that were absent in the photo; a statue could not move up and down on its own because it had no real feet which appeared in the photo). According to this proposal, children are reluctant to consider machines as animals because machines are made of the "wrong stuff", or non-biological stuff. Children know that animals have to be made of "real stuff", or biological stuff. Therefore, these results suggest that young children distinguish animals from self-propelled machines or artifacts and hold some biological expectations about animals but not self-propelled machines, such as of what kind of stuff an object is composed of.

Of course, it is very unlikely that young infant understand that animals should be made of biological stuff. But we wondered whether infants have any quasi-biological expectations about animals, one of which has to do with the notion of insides. Previous work suggests that by 4 years of age children distinguish between the internal and external feature of objects (e.g., Gelman, 2003; Gelman & Wellman, 1991; Simons & Keil, 1995). Young children at least at 3 years of age expect animals and artifacts to have different insides: specifically, they expect animals but not artifacts to have bones, blood, and other biological stuff inside of their bodies. They also understand that insides are vital to how an animal moves and behaves (e.g., R. Gelman, 1990; S. A. Gelman & Gottfried, 1996; Gottfried & S. A. Gelman, 2005). For example, S.

Gelman and Gottfried (1996) showed 3- and 4-year-olds videos that recorded three kinds of objects' transported or self-propelled motions, including animals, wind-up toys, and transparent artifacts. The children were randomly assigned into a transported-motion condition or a moving-alone condition. In the transported-motion condition, the children watched a video in which a human agent touched or grasped an object to move it to a new location. In the moving-alone condition, the children watched a video in which an object traveled through space alone a straight line. After watching the video, all children were asked three questions, (1) "Did a person make this thing move?" (2) "Did something inside this thing make it move?" (3) "Did this thing move by itself?" 4-year-olds were also asked the question, "What do you think is inside this thing?" They found that 3- and 4-year-olds were more likely to attribute the movement to the human agent in the transported-motion condition, and tended to attribute the movement to the object itself in the moving-alone condition. Considering each condition separately, they found that the children in both conditions attributed more artifacts' than animals' motion to the human agent, and attributed more self-propelled motion to animals than to artifacts. In the transported-motion condition, the children tended to attribute the motion to something inside more for animals than for transparent artifacts. In the moving-alone condition, the children tended to attribute the motion to internal causes for both animals and artifacts rather than external causes. But the children explained that animals' motion was caused by itself, and wind-up toy's motion was caused by some internal mechanical parts. S. Gelman and Gottfried also analyzed how 4-year-olds answered what was inside the objects. 4-year-olds tended to provide biological explanations for animals and mechanical or agent explanations for wind-up toys and transparent artifacts. The children in the moving-alone condition were more likely to suggest that mechanical internal parts caused the toys and artifacts to move than the infants in the transported-motion

condition. Based on these and other control results, S. Gelman and Gottfried suggested that young children (1) distinguish between animals and self-propelled artifacts or machines, (2) understand that something inside animals and self-propelled artifacts is able to set them to move, (3) believe the inside of animals are biological stuff, like bones and blood, whereas the internal parts of self-propelled artifacts are mechanical or electrical entities, such as batteries, motors, and electricity.

Recent research also suggests that young infants attend to the insides of novel objects. For example, Welder and Graham (2006) familiarized 14- to 15-month-old infants with novel objects that shared either more obvious surface features or less obvious inside stuff. They found that the infants categorized the objects according to the more obvious surface features when no additional cues were given. However, in one condition, the infants were provided an animacy cue (eyes on the objects); they tended to use the less obvious inside stuff to categorize the objects. These results are consistent with the findings that young children understand that internal properties are essential for the identity of animals. These results may imply that even infants have some rudimentary understanding that the insides of objects are related to their identity.

Infants also expect the inside of an animal to be relevant to how it behaves (e.g., Newman, Herrmann, Wynn, & Keil, 2008). Newman et al. (2008) familiarized a group of 14-month-old infants to two animated cats that each exhibited a different style of self-generated motion. One cat had a red stomach and a red hat, and the other had a blue stomach and a blue hat. Both stomachs and hats were visible, but the stomachs were positioned inside of the cats' bodies and permanently connected to them. During the familiarization, the blue cat swayed back and forth, and the red cat jumped up and down. In the test, the infants saw a novel cat which had either a blue stomach and a red hat, or a red stomach and a blue hat. The novel cat's action was either

congruent with the color of the stomach or with the color of the hat. They found that the infants looked reliably longer when the cat's motion was congruent with the hat than when it was congruent with the stomach, suggesting that the infants believed that it was the internal rather than the external features of an animal that are relevant to its movements.

4.3. The present research

Based on these prior research findings, we suspected that young infants may have quasi-biological expectations about animals' insides. We do not believe that young infants have any specific expectations about what biological stuff is inside animals. Our objective in Experiment 7 was to examine whether infants who identify an object as an animal immediately hold additional quasi-biological expectations about the object. In particular, would infants expect the object to have insides?

The experiment built on two recent research findings: one was that 7-month-olds may already view fur as an animal property (e.g., Pauen & Träuble, 2009), and the other was that 4-month-olds correctly construe rattling noises as produced by loose objects colliding in a hollow space (e.g., Bahrick, 2001, Walker-Andrews, 1994, Wilcox, Woods, Tuggy, & Napoli, 2006). We speculated that if infants categorized a novel self-propelled object with fur as an animal, and immediately assumed that it was solid as opposed to hollow, then they might be surprised if it rattled when shaken (since the rattling sound would suggest loose parts in a hollow space).

Experiment 7

A group of 7-month-old infants (self-propelled/rattling condition) was first familiarized with two events in which either a round object covered with real animal fur (furry-dome event) or a paper-covered cube (smooth-cube event) moved back and forth on an apparatus floor. In test, the infants saw an experimenter's gloved hand shake either the furry dome (furry-dome event) or

the smooth cube (smooth-cube event); both objects made a loud rattling sound when shaken. If the infants viewed the furry dome as an animal and expected an animal to be solid inside, they might be surprised to hear the rattling sound when the object was shaken. Therefore, we predicted that the infants who saw the furry-dome event would look reliably longer than those who saw the smooth-cube event (see Fig. 20).

However, these results could also be interpreted in other ways: (1) the infants were simply surprised to see an experimenter shake an animal, or (2) they were simply surprised to hear a loud rattling noise coming from a soft object. To exclude these alternative interpretations, another two groups of infants were tested in a self-propelled/silent condition and an inert/rattling condition. In the self-propelled/silent condition, infants saw the same familiarization and test events as in the self-propelled/rattling condition except that the furry dome and the smooth cube made no sound when shaken. If the infants in the self-propelled/rattling condition were merely surprised by the experimenter's shaking action on the furry dome, then in the self-propelled/silent condition the infants who saw the furry-dome test event should also look reliably longer than those who saw the smooth-cube test event. However, if the infants in the self-propelled/rattling condition were surprised when the furry dome, an animal, made a rattling sound when shaken, the infants in the self-propelled/silent condition should look about equally at the test events (see Fig. 21).

In the inert/rattling condition, infants again saw events similar to those in the self-propelled/rattling condition, except that the furry dome and the cube were no longer self-propelled: they were placed on a tray which was visibly moved by the experimenter's gloved hand during the familiarization trials. If the infants in the self-propelled/rattling condition were only surprised to hear a rattling sound from a soft object, then in the inert/rattling condition the

infants who saw the furry-dome test event should also look reliably longer than those who saw the smooth-cube test event. However, if the infants in the self-propelled/rattling condition were surprised because the furry dome, an animal, made a rattling sound when shaken, the infants in the inert/rattling condition should look about equally at the test events (see Fig. 22).

Method

Participants

Participants were 48 healthy full-term infants, 24 male (6 months, 17 days to 8 months, 5 day, $M = 7$ months, 15 days). Another 3 infants were tested but excluded because of fussiness. 16 infants were randomly assigned into the self-propelled/rattling condition ($M = 7$ months, 18 days), 16 infants to the self-propelled/silent condition ($M = 7$ months, 18 days), and the others to the inert/rattling sound condition ($M = 7$ months, 10 days). Within each condition, half the infants saw the furry dome shaken in the test trial, and half saw the smooth cube.

Apparatus

The infant sat on a parent's lap in front of a display booth (106 cm $\times$ 103.5 cm $\times$ 46 cm) with a large opening (39 cm $\times$ 94 cm) in its front wall; between trials, a supervisor lowered a muslin-covered frame (61 cm $\times$ 94 cm) in front of this opening. Parents were instructed to remain silent and to close their eyes during the test trial.

The floor of the apparatus was made of foam board and covered with beige granite-patterned contact paper. The back wall was made of white foam board. Between the bottom of the back wall and the apparatus floor was a 0.5 cm gap, covered with fringed white cloth. A window (38 cm $\times$ 51.5 cm) in the right wall of the apparatus was covered with a white fringed curtain. The furry dome (about 19 cm $\times$ 19 cm $\times$ 19 cm at its largest points) consisted of a round cardboard base covered with beaver fur. The smooth cube (18 cm $\times$ 18 cm $\times$ 18.5 cm) was made

of foam board and covered with brown package paper. The edges of the box were covered with dark brown tapes. In the familiarization trials of the self-propelled/rattling and the self-propelled/silent conditions, each object was attached to a narrow wooden stick (5 cm × 30 cm × 0.5 cm) covered with the same beige granite-patterned contact paper as the apparatus floor. Each wooden stick protruded through the gap between the back wall and the apparatus floor, and was moved by an experimenter behind the back wall. In the familiarization trials of the inert/rattling condition, both objects were placed on a cardboard tray (22.5 cm × 29 cm × 5 cm) covered with yellow contact paper. In the self-propelled/rattling and inert/rattling conditions, a bag of 22 jingle bells (the size of each bell was about 1 cm in diameter) was placed inside the furry dome and the smooth cube.

Event

Self-propelled/rattling condition

Familiarization events

Furry-dome event. The furry dome rested on the apparatus floor (1 s), 26.5 cm from the front edge and 52 cm away from the right wall. An experimenter surreptitiously moved the stick attached to the bottom of the object so that the furry dome appeared to move back and forth by itself on the apparatus floor. The furry dome first moved 24.5 cm toward to the right of the apparatus (3 s) and paused (1 s). Then, the object reversed direction and returned to its original position (3 s). After another 1-second pause, the object 24.5 moved to the left (3 s), paused 1 second, and then moved back to the center of the apparatus (3 s). The event cycle was repeated once (16 s). Then, the furry dome remained stationary on the apparatus floor until the trial ended.

Smooth-cube event. The event was identical to the furry-dome event except that the smooth cube was used.

Test events

Furry-dome event. The furry dome was positioned at the center of the apparatus without the stick. Gloved hands first (35.5 cm from the object) rested at the edge of the window in the right wall of the apparatus (1 s). The hands then reached for and grasped the furry dome (1 s). The hands lifted the furry dome 7.5 cm above the apparatus floor (2 s) and shook it for 2 seconds. When shaken, the jingle bells inside the dome made a loud rattling sound. After shaking the dome, the hands put it down on the apparatus floor (2 s) and paused (2 s). The hands repeated the actions of lifting, shaking, and lowering the dome on the apparatus floor twice with a 2-s pause between the two repetitions (14 s). Then, the hands released the dome and rested next to it (1 s) on the apparatus floor until the trial ended.

Smooth-cube event. The event was identical to the furry-dome event except that the smooth cube was used.

Self-propelled/silent condition

The events were identical to those in the self-propelled/rattling condition except no jingle bells were placed inside of the furry dome or the smooth cube and therefore there was no sound when either object was shaken in the test event.

Inert/rattling condition

The events were identical to those in the self-propelled/rattling condition except the furry dome and the smooth cube were placed on a yellow tray which was moved back and forth on the apparatus floor in the familiarization events.

Procedure

The infants in the three conditions were first familiarized with the furry dome (furry-dome event) and the smooth cube (smooth-cube event) in four alternate trials. The order of the

two events was counterbalanced within infants. After the familiarization trials, the infants received one test trial appropriate to their conditions. Infants who saw the furry-dome event first in the familiarization trials saw the furry-dome event in the test trial; infants who saw the smooth-cube event in the familiarization trials saw the smooth-cube event in the test trial.

Familiarization events. The pretrial of the familiarization events lasted about 32 seconds. The main trial of each familiarization trial ended when the infants either (1) looked away for 1 consecutive second after having looked at the event for at least 5 seconds, or (2) looked for 20 cumulative seconds without looking away for 1 second.

Test events. The pretrial of the test events lasted about 25 seconds. The main trial of the test trial ended until the infants either (1) looked away for 1 consecutive second after having looked at the event for at least 6 seconds, or (2) looked for 20 consecutive seconds without looking away for 1 second.

During each experimental session, one camera captured an image of the events, and another camera captured an image of the infant. The two images were combined, projected onto a TV set located behind the apparatus, and monitored by the supervisor to confirm that the events followed the prescribed scripts. Recorded sessions were also checked offline for accuracy.

Coding

Each infant's looking behavior was monitored by two observers who viewed the infant through peepholes in large cloth-covered frames on either side of the apparatus. Interobserver agreement during the familiarization trials averaged 89% pre trial per infant. Although neither observer could reliably guess in which order the familiarization events were presented to the infants, the observers could potentially know which condition that infants received based on the cues available in the familiarization and test trials (e.g., whether the object produced a rattling

sound in the test trial, or whether the objects were moved on a tray by an experimenter through the side window in the familiarization trials). To avoid this possible observer bias, a naïve coder coded the test trials frame-by-frame from edited silent videos. All edited test trials started when the experimenter's hands fully rested next to the object after shaking it three times. In this way, the coder could not know which condition the infants received. Each test trial ended when the infants (1) looked away for 1 consecutive second after having looked for the event at least 6 cumulative seconds, or (2) looked for 20 cumulative seconds without looking away for 1 second. A second coder also coded all the edited videos of the test trials and agreed with the first coder on 97% of coded video frames. Trials in which agreement was less than 90% (6/48) were resolved through discussion.

In the final analyses, the looking times recorded by the primary observer during the experiment were used in the analyses of the familiarization data, and the looking times recorded by the naïve coder who coded the edited test videos were used in the analyses of the test data. Preliminary analyses yielded no interactions of condition and event with either sex or order in the familiarization trials, $F(2, 36) = 1.69$, $p = 0.20$, and no interactions of condition and event with sex in the test trials, $F(2, 36) = 1.56$, $p = 0.22$; the data of the familiarization trials were therefore collapsed across the order and sex, and the data of the test trials were collapsed across sex in subsequent analyses.

Results and Discussion

The infants' looking times in the familiarization trials were averaged across pairs and analyzed using a two-way ANOVA with condition (self-propelled/rattling, self-propelled/silent, or inert/rattling) as a between-subjects factor and event (furry-dome or smooth-cube) as a within-subjects factor (see Fig. 23). The analyses yielded a significant main effect of condition, $F(2, 36)$

= 4.57, $p < 0.02$. The effect was mainly due to the significant shorter mean looking times of the infants in the self-propelled/rattling condition than those of the infants in the other two conditions (self-propelled/rattling: $M = 7.6$ s, $SD = 2.3$; self-propelled/silent: $M = 10.1$, $SD = 3.2$; inert/rattling: $M = 8.7$, $SD = 2.9$). This difference might be random. There were no significant main effect of event, $F(1, 45) = 2.30$, $p = 0.14$, and no significant condition $\times$ event interaction, $F(2, 45) < 1$. These results showed that infants in each condition looked about equally at both furry-dome (self-propelled/rattling: $M = 7.9$ s, $SD = 2.6$, self-propelled/silent: $M = 10.7$ s, $SD = 3.4$, inert/rattling: $M = 9.0$ s, $SD = 2.7$) and smooth-cube (self-propelled/rattling: $M = 7.4$ s, $SD = 2.1$, self-propelled/silent: $M = 9.4$ s, $SD = 3.0$, inert/rattling: $M = 8.5$ s, $SD = 3.1$) events, suggesting that the two familiarization events were equally interesting to the infants in each condition.

The infants' looking times during the test trials were analyzed using a two-way ANOVA with condition (self-propelled/rattling, self-propelled/silent, or inert/rattling) and event (furry-dome or smooth-cube) as between-subjects factors. The main effects of condition, $F(2, 42) = 4.77$, $p < 0.01$, and event, $F(1, 42) = 5.98$, $p < 0.02$., were significant. The analysis also yielded a significant condition $\times$ event interaction, $F(2, 42) = 3.61$, $p < 0.05$. Planned comparisons revealed that in the self-propelled/rattling condition, the infants who saw the furry-dome event ($M = 12.1$ s, $SD = 3.0$) looked reliably longer than those who saw the smooth-cube event ($M = 8.4$ s, $SD = 2.2$), $F(1, 42) = 12.94$, $p < 0.001$; in the self-propelled/silent condition, the infants looked about equally at the furry-dome ($M = 8.1$ s, $SD = 2.3$), and smooth-cube ($M = 7.6$ s, $SD = 1.3$) event, $F(1, 42) < 1$, and the same looking pattern was found in the inert/rattling conditions (furry-dome: $M = 8.2$ s, $SD = 1.6$; smooth-cube: $M = 8.0$ s, $SD = 1.3$), $F(1, 42) < 1$. The

Wilcoxon sum-rank tests also revealed the same results (self-propelled/rattling: $W = 47$, $p < 0.05$, self-propelled/silent: $W = 66$, $p = 0.88$, inert/rattling: $W = 57.5$, $p = 0.98$).

Additional planned comparisons revealed that the infants in the self-propelled/rattling condition looked reliably longer at the furry-dome test event than those in the self-propelled/silent condition, $F(1, 42) = 26.40$, $p < 0.0001$, and those in the inert/rattling condition, $F(1, 42) = 14.29$, $p < 0.0005$.

General Discussion

Experiment 7 investigated whether 7-month-old infants have quasi-biological expectations about an object that they categorize as an animal, particularly, whether they expect it to have insides. The results indicated that in the self-propelled/rattling condition, 7-month-old infants who saw the furry-dome test event looked reliably longer than those who saw the smooth-cube test event, suggesting that they were surprised when the furry dome, but not the cube, made a rattling noise when shaken. In the self-propelled/silent condition, the furry dome and the cube were both silent when shaken. Infants now looked about equally at the two test events, suggesting that the infants in self-propelled/rattling condition were not merely surprised to see the experimenter shake an animal, the self-propelled furry dome. In the inert/rattling, the furry dome and the cube both rattled when shaken, but they were no longer self-propelled: during the familiarization trials, the experimenter visibly moved each object on a tray across the apparatus. Infants again looked about equally at the two test events, suggesting that the infants in self-propelled/rattling were not merely surprised to hear a furry object produce a rattling noise. Infants were thus surprised when a self-propelled furry object (but not a self-propelled cube or an inert furry object) rattled when shaken. Together, the current results suggest that, by 7 months of age, infants may expect self-propelled objects with animal-like properties to have insides.

However, an alternative interpretation of the present results is that the infants in the self-propelled/rattling condition might be surprised to hear the rattling sound from the furry dome simply because they have had little opportunity to observe furry objects rattle—they may associate rattling sounds with other, rattle-shaped objects. Just like a dog barks, but it doesn't make a cat sound. In other words, the infants who saw the furry-dome test event in the self-propelled/rattling condition might have looked longer than those who saw the smooth-cube test event not because they expected that the inside of the furry dome was full as opposed to hollow, but because they had never heard a rattling sound come from a self-propelled furry object. They did not associate rattling sound with furry objects. To test this alternative hypothesis, in an ongoing experiment, 7-month-old infants are shown similar familiarization and test events except that the experimenter does not interact with the objects during the test trials: the furry dome and the smooth cube produce the rattling sounds on their own, while resting on the apparatus floor (e.g., as though they were growling). If the alternative interpretation is correct, then in the ongoing experiments the infants who watch the furry-dome event should look significant longer than those who see the smooth-cube event. In contrast, if the infants in the self-propelled/rattling condition of Experiment 7 were surprised by the rattling noise because they interpreted it as loose parts hitting each other in a hollow space and expected the furry dome to be full inside as opposed to be hollow, then infants in the ongoing experiment should look about equally at both test events, because the rattling sounds are now more likely to be interpreted as a growl than as loose parts rattling in a hollow space.

Assuming that the results of the ongoing experiment disconfirm the alternative hypothesis, then the present results and the expected results of the ongoing experiment would provide evidence that infants have some quasi-biological understanding of animals: their concept

of animal contains, by 7 months of age, the expectation that the inside of an animal should be full, as opposed to hollow.

Our results provide evidence that infants have some quasi-biological expectations about self-propelled objects. These results are consistent with the previous research on young children's understanding of animals' insides (Keil, 1999; Simons & Keil, 1995; Walker, 1999). Though, unlike young children, infants may not know whether animals must be made of "right" stuff or "biological stuff", our results do suggest that infants believe that the insides of animals and other self-propelled objects are different. The understanding of animals' insides may imply that a rudimentary biological domain already exists in infancy. The core concept for this domain is animal.

Besides the insides of animals, do infants have any other quasi-biological expectations about animals, such as growth? In Chapter 2, we asked whether young infants would believe some appearances changes are possible when a self-propelled object is an animal. One of these changes is growth: the size of an animal becomes bigger over time.

The research on young children's understanding of growth and biological transformations may provide some hints to answer these questions. Take the research by Rosengren and his colleagues (1991) as an example. Rosengren and his colleagues first presented 3- to 6-year-old children and adults with pictures of baby animals and novel artifacts and asked them to choose which of two other pictures was the animal as an adult or the artifact after it had been around for a very long time. When the size of the objects in the pictures changed, the 3-year-olds believed that animals (but not artifacts) would get larger (but not smaller) over time. When the size and color or the size, color, and shape of the animals (metamorphosis) in the pictures changed, the older children and adults believed that some animals could change size, shape, and color across

the life span (e.g. from caterpillars to butterflies), but the 3-year-olds tended to expect the color and shape of animals to remain constant throughout the natural growth process.

These findings indicate that 3-year-old children are reluctant to view shape and color changes as possible even for animals, but they tend to believe that animals but not artifacts can become bigger overtime. This may suggest that young children believe that size changes are related to the biological properties of animals. How about infants? Would they accept size changes of a self-propelled object as possible? If infants view a self-propelled object as only a physical entity, like the artifacts in the study by Rosengren et al., they would view the size change as impossible. The question is whether they would view the size change as possible if they also construe a self-propelled object as an animal at the same time. If the answer is yes, this may suggest that infants might have some quasi-biological expectations about growth: they might expect animals to grow bigger over time through eating. Further research is necessary to investigate all these questions.

CHAPTER 5

CONCLUSION

From early on, young infants divide objects around them into different categories which guide them to acquire relevant knowledge about the world. On one hand, they form specific basic-level categories, such as cats, dogs, cups, and shoes, by associating together their similar perceptual characteristics, like size, shape, color, texture, and so on. On the other hand, young infants also possess broad, abstract object categories. According to the core-concept view on how infants attain these general categories, infants are born with domain-specific principles that help them organize their knowledge of the world in a coherent way and to explain, predict, and interpret events in these domains (e.g., Carey, 1985,1999; Gelman, 1990, 2002; Gelman et al., 1995; Leslie, 1984a, 1994; S. Gelman & Gottfried, 1996; Gottfried & S. Gelman, 2005; Keil, 1995; Subrahmanyam et al., 2002; Wellman & Gelman, 1997). In each domain, infants divide objects into fundamentally different kinds or ontological categories, in accordance with the corresponding causal principles.

Previously, researchers have focused mainly on three specific domains: the physical, psychological, and biological domains (e.g. Carey & Spelke, 1994; Keil, 1995; Wellman, & Gelman, 1997; Wellman, Hickling, & Schult, 1997). In the present research, we explored infants' knowledge and expectations about the ontological entities in these three domains. In the physical-reasoning domain, infants form a self-propelled-inert distinction in terms of a notion of internal energy (e.g., Gelman, 1990, 2002, Leslie, 1984, 1994, 1995). In the psychological-reasoning domain, infants distinguish agents from other objects in accordance with a notion of internal states (e.g. Csibra, 2008; Baillargeon et al., 2009). Lastly, in the biological-reasoning

domain, infants may distinguish animals from non-animals and may have quasi-biological expectations about animals.

5.1. Infants' expectations about self-propelled objects, agents, and animals

Expectations about self-propelled objects with prominent parts. Building on previous findings about infants' expectations about self-propelled and inert objects, in Chapter 2 we investigated further infants' expectations for self-propelled objects. Specifically, we asked whether infants believe that self-propelled objects can produce some changes in their parts, presumably through the application of internal energy. At the same time, we were also interested in whether infants understand that there are limitations to the sorts of changes that an application of internal energy can produce in a self-propelled object's parts.

Across four experiments, we examined four different ways in which a self-propelled object's parts might undergo change: in appearance changes, a part retained its location, position, and orientation but changed its size, shape, pattern, and color; in location changes, a part moved from one side of the object to the other; in position changes, a part remained on the same side of the object but moved up or down; and finally in orientation changes, a part preserved its location and position on the object but changed its orientation. Results indicated that 5-month-old infants detected a violation when the object's parts changed appearance (Experiment 1) or location (Experiment 2), but not when they changed position (Experiment 3) or orientation (Experiment 4). These and other control results suggest that, by 5 months of age, infants believe that self-propelled objects can use their internal energy to move their parts (e.g., reorient them or shift them up or down somewhat), but not to alter their appearance or reattach them at new locations.

Expectations about inert agents. Supported by increasing research evidence, the system-based approach proposes that young infants view both human and non-human objects as agents

and attribute to them various internal states (e.g., goals, dispositions, beliefs, and knowledge) to make sense of their actions (e.g., Csibra, 2008; Baron-Cohen, 1994; Gergely & Csibra, 2003; Gergely, et al., 1995, Johnson, 2000; Leslie, 1994, 1995; Luo & Baillargeon, 2005; Premack, 1990; Premack & Premack, 1995,1997; Saxe et al., 2007; Shimizu & Johnson, 2004; Surian et al., 2006). A critical question raised by this view is how infants identify a novel non-human object as an agent. On one hand, previous research has indicated that self-propulsion is not a sufficient cue for young infants to categorize a novel non-human object as an agent (e.g., Csibra, 2008; Johnson et al., 2007; Kamewari et al., 2005; Shimizu & Johnson, 2004). On the other hand, self-propulsion may not be necessary for infants to view an object as an agent if infants believe that agents are objects that provide evidence of possessing internal states. In Chapter 3, we directly examined this hypothesis by asking whether young infants believe that an inert object can be an agent.

Two experiments were conducted to investigate this question. In Experiment 5, 14-month-old infants viewed a beeping box which never moved on its own as an agent and attributed to it a preference. At the same time, the infants were surprised to see the box remain suspended in midair when released in Experiment 6, suggesting that they viewed the box as inert and expected it to fall when released in midair. Taken together, the results of Experiments 5 and 6 suggest that self-propulsion is not necessary for infants to identify an object as an agent: by the age of 14 months, infants believe that an agent can be inert. Together, previous results and the current results thus suggest that self-propulsion is neither sufficient nor necessary for infants to identify an object as an agent.

Expectations about animals' insides. According to recent proposals, infants view objects that are both self-propelled and agents as animals (e.g., Mandler, 2010). In this view, infants'

concept of animal is merely the combination of physical and psychological attributes: it says nothing about the biological properties of animals. However, based on previous research on young children's biological understanding (e.g., Gelman, 1990, 2000; S. A. Gelman & Gottfried, 1996; Gottfried & S. A. Gelman, 2005; Subrahmanyam et al., 2002), we speculated that, after determining that an object is a self-propelled agent, infants might immediately have additional, quasi-biological expectations about the object that go beyond its physical and psychological attributes. In Chapter 4, we examined whether infants who construe an object as an animal hold one particular quasi-biological expectation: specifically, do they expect the object to have insides? The present research represented a first attempt at addressing this question.

There are two possible ways that infants may identify an object as an animal. First, according to this view of infants' concept of animal, an object would be viewed as an animal if it provides clear evidence of self-propulsion and agency. Second, infants learn through experience what characteristic, surface properties, parts, motions, and behaviors, are typically associated with animals (e.g., Arterberry & Bornstein, 2002; Mandler & McDonough, 1996; Rakison, 2003; Rakison & Poulin-Dubois, 2001; Subrahmanyam et al., 2002). In particular, they tend to view self-propelled objects with feature such as faces, eyes, fur, and biological motions as animals.

In the present research, we showed 7-month-old infants a self-propelled object covered with animal fur and a self-propelled paper box. According to the second way that infants identify a novel object as an animal, they should view the self-propelled furry object but not the self-propelled paper box as an animal. In the self-propelled/rattling condition of Experiment 7, the infants saw a self-propelled furry-dome and a self-propelled smooth cube in alternation in the familiarization trials. In the test trial, either the furry dome or the smooth cube was shaken by gloved hands, causing it to make a rattling sound. The results indicated that the infants who saw

the furry-dome test event looked reliably longer than those who saw the smooth-cube test event, suggesting that they were surprised when the furry object, but not the cube, rattled when shaken. In the self-propelled/silent condition, the furry object and the cube were both silent when shaken. Infants now looked equally at the two test events, suggesting that the infants in the self-propelled/rattling condition were not just surprised by the shaking action. In the inert/rattling condition, the furry object and the cube rattled when shaken, but they were no longer self-propelled: during the familiarization trials, the experimenter's gloved hand visibly moved each object on a tray across the apparatus. Infants again looked equally at the two test events, suggesting that the infants in the self-propelled/rattling condition were not surprised by hearing a rattling sound emerge from a soft object. An ongoing experiment addresses another alternative interpretation of the self-propelled/rattling condition: it might be suggested that infants often encounter rattling sounds in every day life, but rarely from self-propelled furry objects. Thus, the effect might be simply due to infants looking longer at a deviation from everyday experience. Another control condition is being conducted to examine this possibility. If infants are not surprised by the rattling sound coming from the self-propelled furry dome or the self-propelled smooth cube when they are not shaken by the experimenter, but simply rest on the apparatus floor, then it will suggest that the infants in the self-propelled/rattling condition were not surprised by a deviation from objects previously associated with rattling sounds. Together, the present results and the expected results of the ongoing experiment may suggest that when 7-month-olds categorize an object as an animal, they immediately expect the object to be full inside as opposed to be hollow.

5.2. The relation between the concepts of self-propelled object, agent, and animal

As discussed above, infants form domain-specific, fundamentally different object categories. In each domain, infants interpret and predict the outcomes of events in terms of the different kinds of objects involved. In this way, the ontological categories of different domains seem to be fundamentally orthogonal to each other. For example, the distinction between self-propelled and inert objects is crucial for infants to understand and predict the outcomes of physical events, but not essential to understand psychological or biological events. However, it is reasonable to believe that these ontological distinctions overlap with each other because objects can be categorized as different kinds of entities in multiple domains simultaneously. As humans, we are self-propelled objects, intentional agents, and bipedal animals at the same time.

Self-propelled objects and agents. According to previous research on infants' physical reasoning, self-propelled objects are objects that possess internal energy. This internal source of energy enables a self-propelled object to control its own and other objects' motion. Previous work suggests that infants view an object as self-propelled if it gives evidence of possessing an internal source of energy. This evidence seems to consist of changes in the object's motion states that cannot be explained by an external force, such as the object initiating its motion, resisting moving when hit, or remaining suspended when released in midair.

If infants perceive a self-propelled object's action as intentional, they view it as an agent. That is, some self-propelled objects are intentional agents. However, previous research also suggests that not all self-propelled objects are agents: self-propulsion is not sufficient for infants to identify an object as an agent. In addition, the present research suggests that self-propulsion is not necessary for infants to view an object as an agent either. In other words, agents can be inert too. Putting together, previous and the current results, it appears that infants look for evidence of

internal states to identify a novel object as an agent. This evidence may consist of behaviors that express different internal states. For example, infants view a box as an agent when it beeps contingently to an experimenter's utterances because the contingent beeps show two different internal states: informational states (the box perceives the experimenter's utterance) and motivational states (the box beeps to the experimenter to fulfill its communicational goal).

Animals as self-propelled agents. Researchers have suggested that for young infants animals may be self-propelled agents, pointing to an overlap between the concepts of self-propelled objects and agents. The question is whether infants interpret and predict the events involving those objects only in terms of the causal principles in the physical and psychological domains. If this is the case, infants may not have a separate biological-reasoning domain. Some researchers proposed that the biological-reasoning domain is derived from the psychological-reasoning domain when children become 4 years of age (e.g., Carey, 1985). However, the current research examined whether from early on infants may have some rudimentary knowledge about animals, which may be the beginning of the biological-reasoning domain. This knowledge would consist of quasi-biological expectations about these objects. For example, as shown in the current research, 7-month-old infants expect an animal to be full inside as opposed to be hollow.

In other words, previous results as well as the current research suggest that young infants may already engage in reasoning that is biological in nature. The combination of self-propelled objects and agents would bring out a separate concept of animals that would be the core concept in infants' biological-reasoning domain.

5.3. Infants understanding of objects' internal attributes

The present research provides additional support for the core-concept view on how infants categorize objects in a domain-specific manner. Infants distinguish self-propelled and

inert objects in terms of a notion of internal energy in the physical-reasoning domain, identify agents in terms of a notion of internal states in the psychological-reasoning domain, and hold quasi-biological expectations about animals in terms of a notion of insides. In each domain, infants identify the relevant ontological entities and reason about them in accordance with their internal, non-obvious attributes rather than solely in terms of their external, obvious, perceptual properties.

These results are consistent with previous findings that infants and young children are good at reasoning about a range of non-obvious properties (e.g., Gelman & Kalish, 2006; Cohen & Cashon, 2006; Gelman, 2009; Mandler & McDonough, 1996; Newman, Herrmann, Wynn, & Keil, 2008; Welder & Graham, 2006). Infants' capacity to reason about objects beyond their obvious features is consistent with the essentialism argument of children's reasoning (e.g., Gelman & Wellman, 1991; Gelman, 2003) and the core-concept view. It also challenges the experience-based view which proposes that infants and young children are bound to the perceptual features of the world around them (e.g., Rakison, 2002; Sloutsky & Fisher, 2004). However, this does not mean that infants have a clear understanding of the internal attributes of objects; instead, they have very vague notions of underlying causes or internal substance of objects, which are sometimes referred to a sort of "placeholders" (e.g., Gelman, 2009; Medin & Ortony, 1989).

An interesting question is whether infants have any idea about the relations between objects' internal attributes, like internal energy, internal states, and internal substance. For animals, both internal energy and internal states are related to their internal substance. Animals' internal substance is the source of their internal energy and also may influence their internal states. Though we do not believe that infants have an elaborate understanding of the links

between these internal properties, previous research does suggest that young infants have started to attend to these links. For example, infants realize that internal substance is relevant to what kind of self-generated behavior animals can perform (e.g., Newman, et. al, 2008). Infants may generalize food preference across the same kind of animals, but may not generalize their preference for other objects (e.g., Setoh, & Baillargeon, 2010).

In conclusion, through three research projects, the current research examined infants' understanding of self-propelled objects, agents, and animals. The results support the core-concept view which states that infants divide objects into broad, abstract categories in accordance with the causal principles in specific reasoning domains. In the physical-reasoning domain, infants distinguish self-propelled from inert objects in terms of a notion of internal energy. Infants endow self-propelled objects with an internal source of energy which enables those objects to control their motion. The first research project indicated that 5-month-old infants understand that a self-propelled object can use its internal energy to produce orientation and position changes but not location and appearance changes in its parts. The second project showed that 14-month-old infants believed that an agent can be inert, suggesting that self-propulsion is not necessary for infants to identify a novel non-human object as an agent. The last project may suggest that 7-month-old infants believe that animals must be full inside.

FIGURES

Figure 1. Schematic drawing of the familiarization and test events used in the inert and self-propelled conditions of the experiment by Luo et al. (2009).

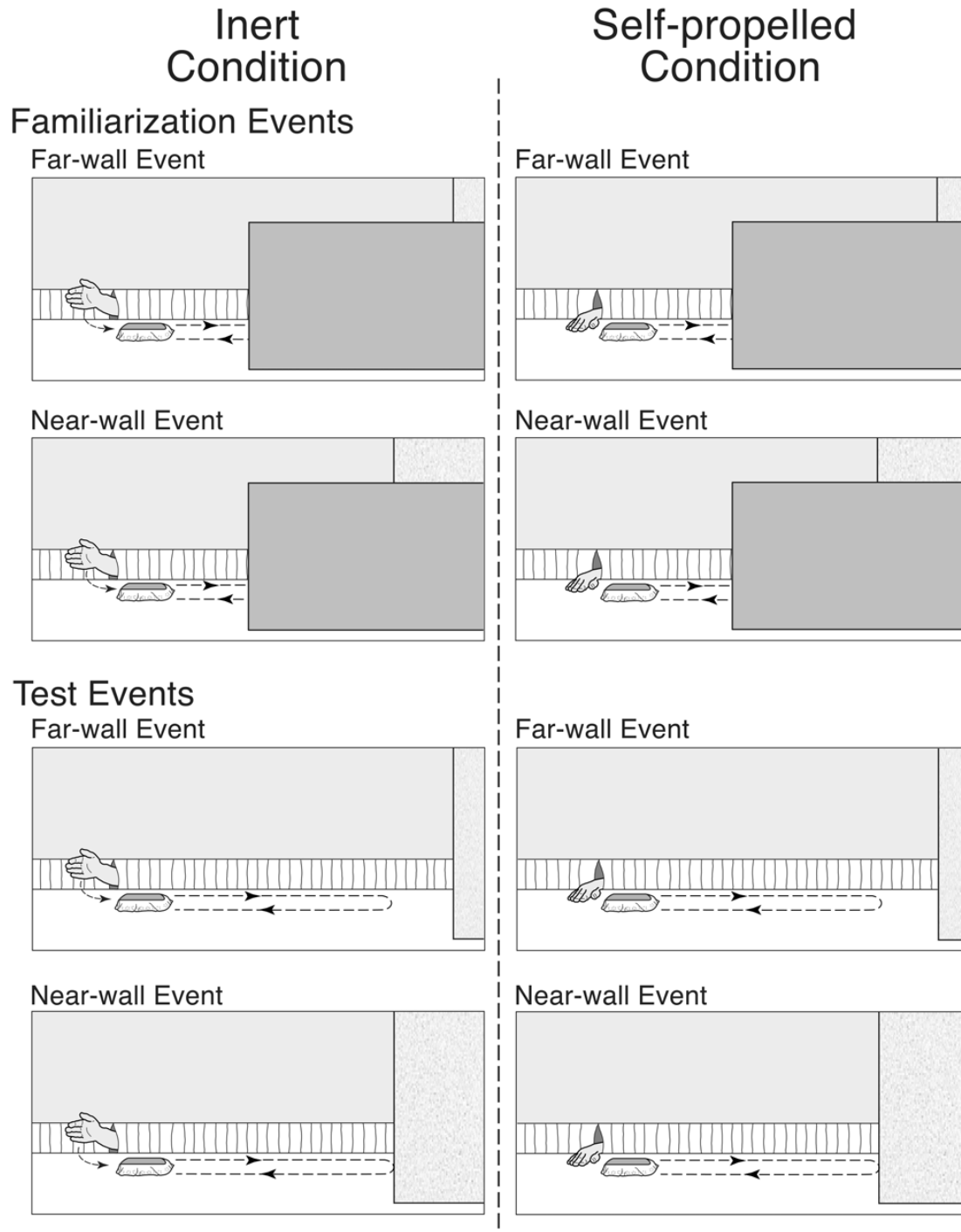


Figure 2. Schematic drawing of the familiarization and test events used in the one and two-screen conditions of the experiment by Luo et al. (2009).

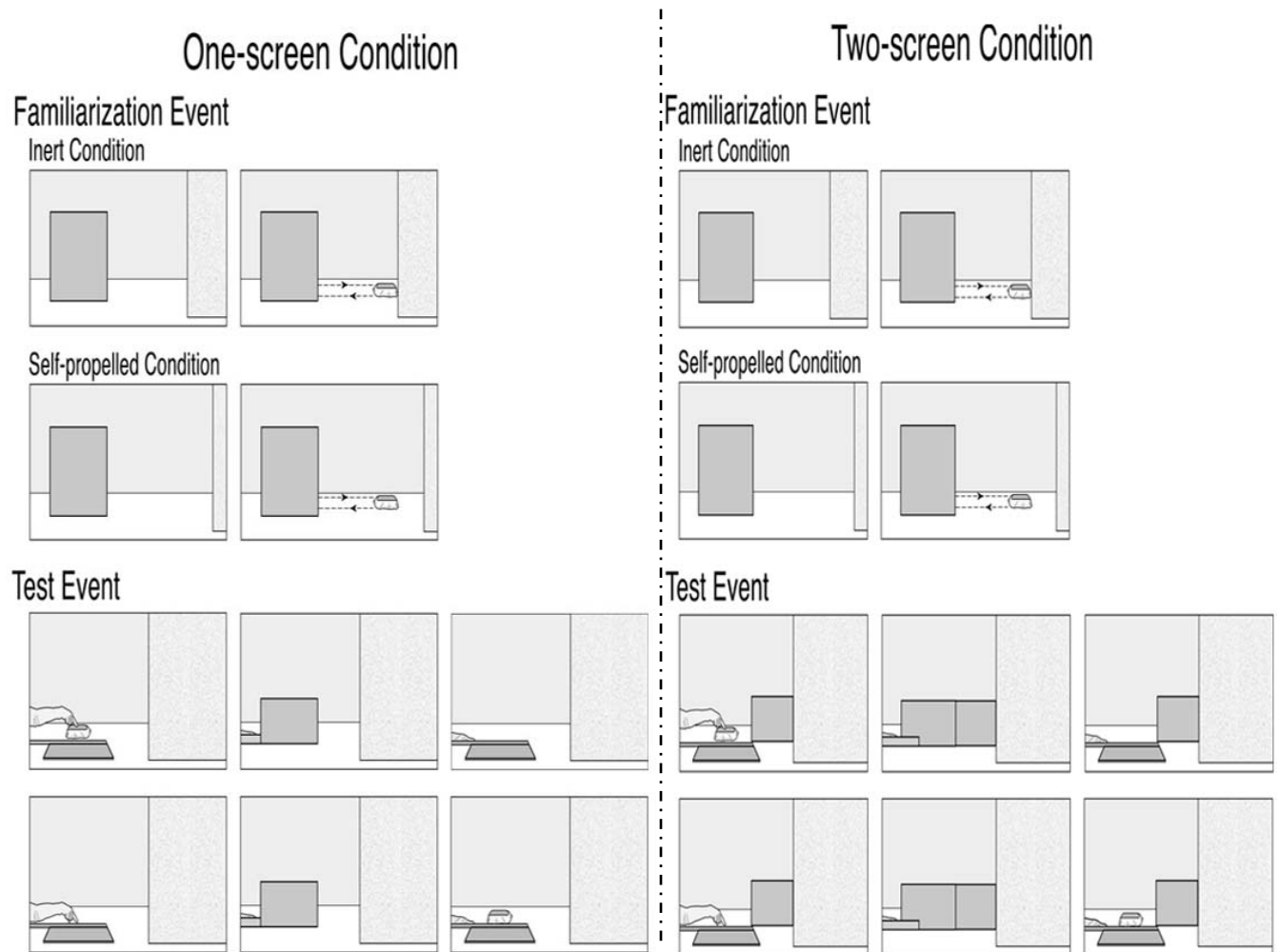
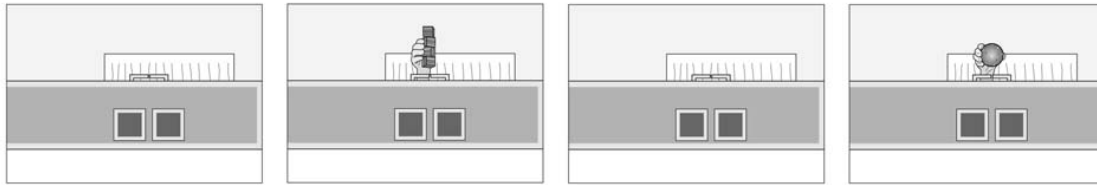


Figure 3. Schematic drawing of the familiarization and test events used in the experimental condition of the experiment by Wu et al. (2006, 2010).

Familiarization Event

Inert Condition

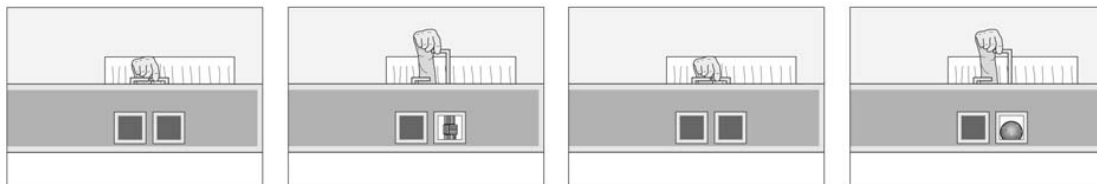


Self-propelled Condition



Test Events

One-window Event



Two-window Event



Figure 4. The stimuli used in Experiments 1-4. A-B, the “tail” box in Experiment 1; C-D, the “arm” box in Experiment 2; E-F, the “arm” box in Experiment 3; G-H, the “tail” box in Experiment 4; I-J, the “Ear” box in further results of Experiment 4.

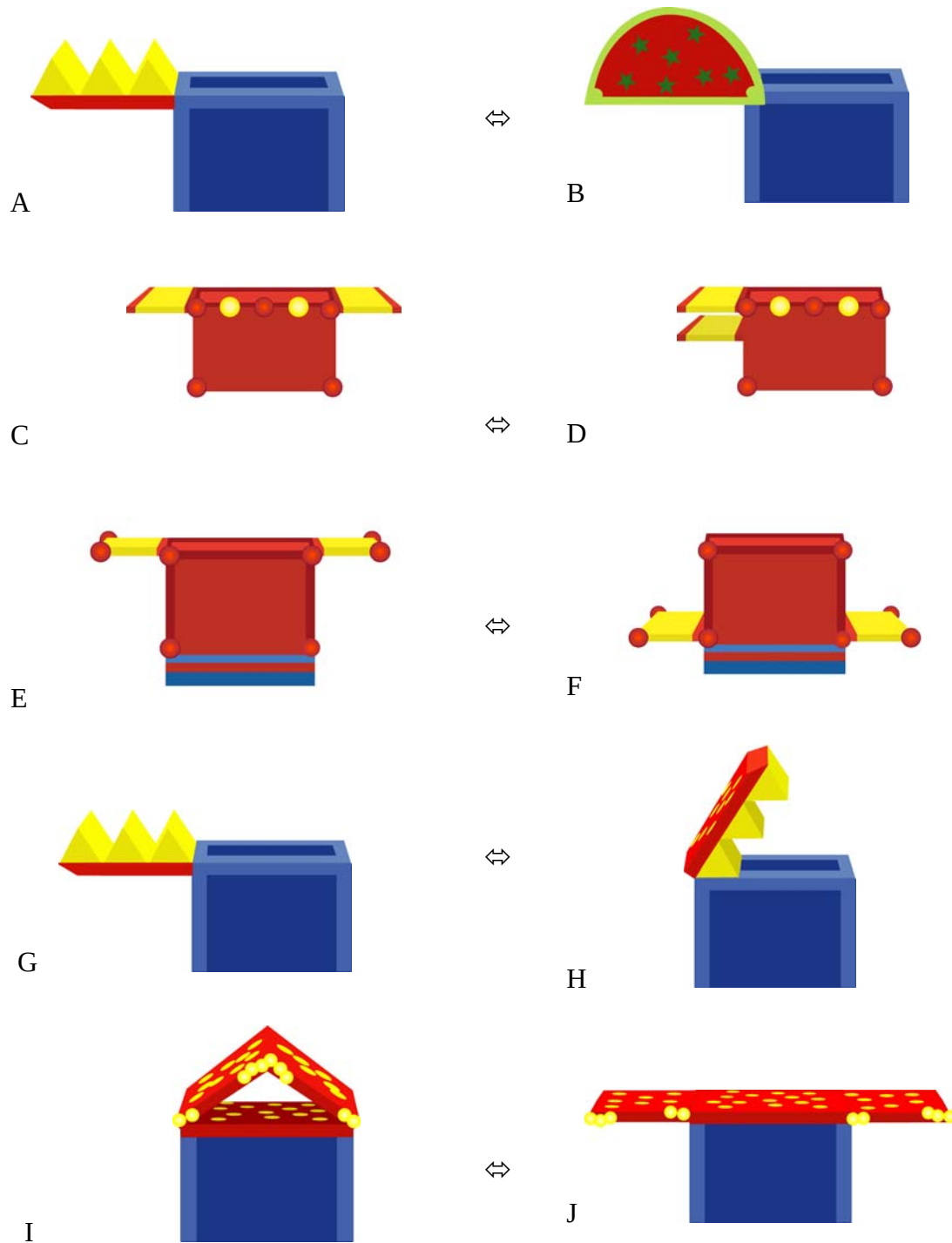
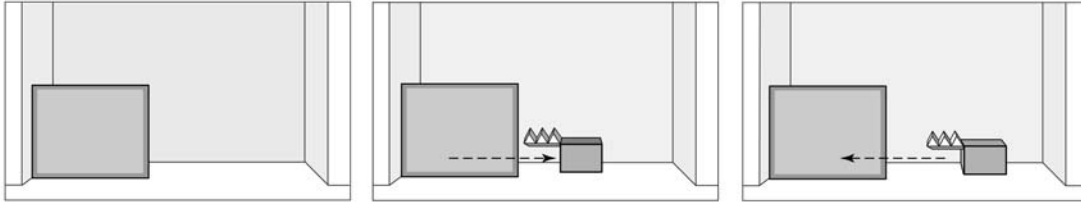


Figure 5. Schematic drawing of the familiarization and test events used in Experiment 1.

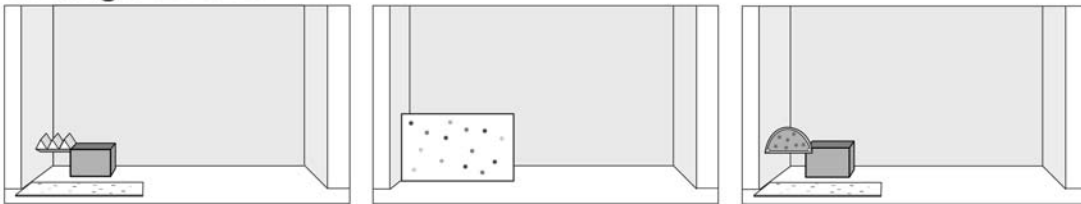
Familiarization Event

Self-propelled Condition



Test Events

Change Event



No-change Event

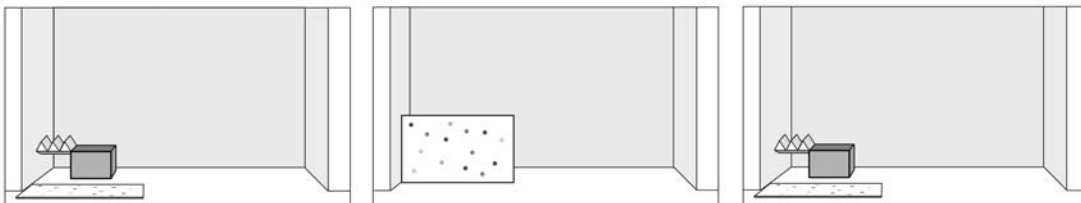


Figure 6. Mean looking times of the test events in Experiments 1 and 2.

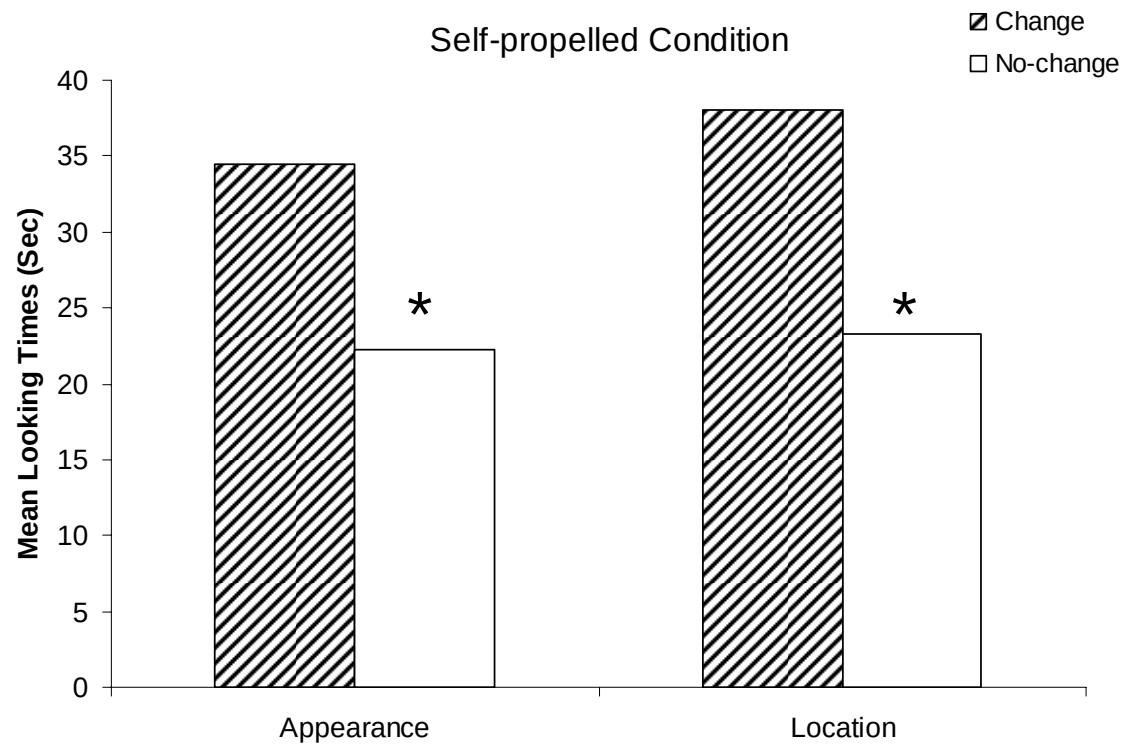
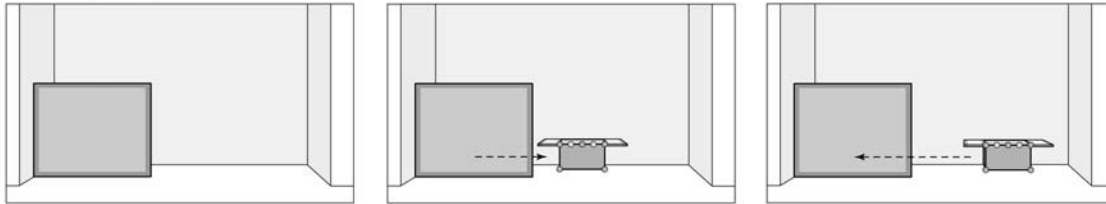


Figure 7. Schematic drawing of the familiarization and test events used in Experiment 2.

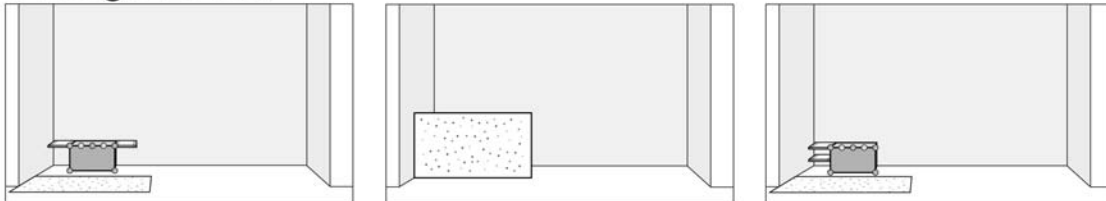
Familiarization Event

Self-propelled Condition



Test Events

Change Event



No-change Event

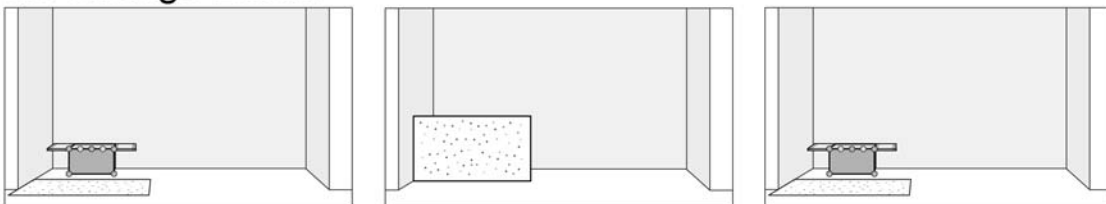
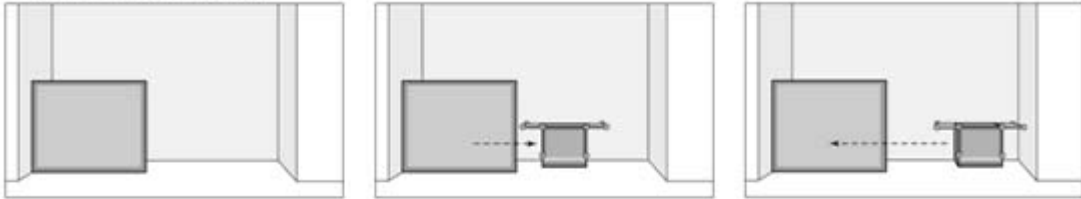


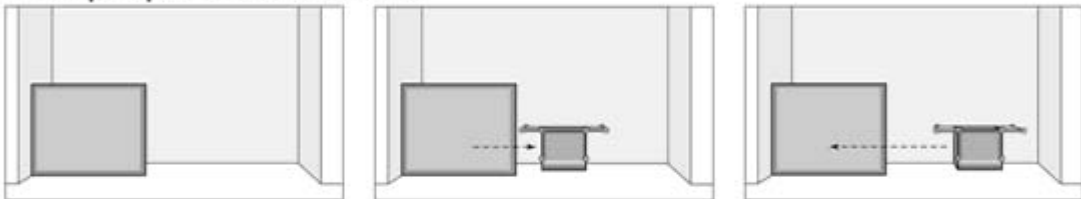
Figure 8. Schematic drawing of the familiarization and test events used in Experiment 3.

Familiarization Event

Inert Condition

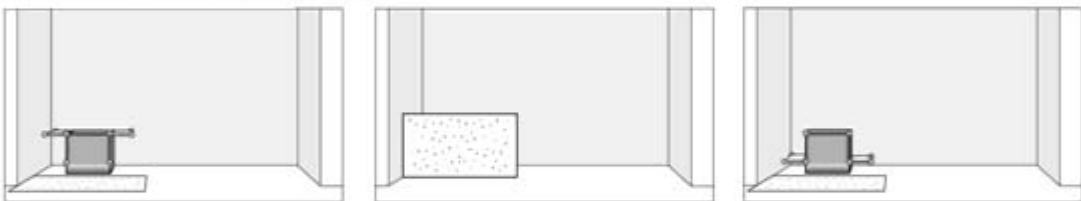


Self-propelled Condition



Test Events

Two-arm-change Event



One-arm-change Event



No-change Event

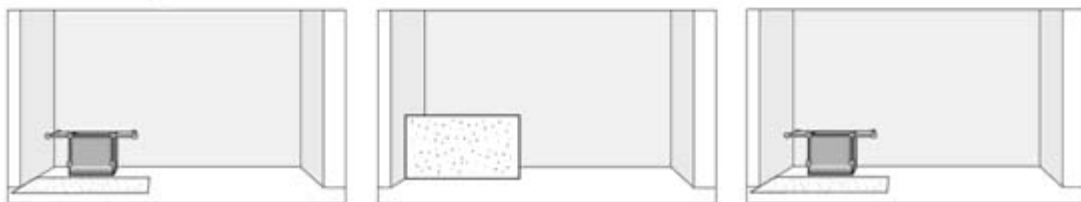


Figure 9. Mean looking times of the test events in Experiment 3 and the further results.

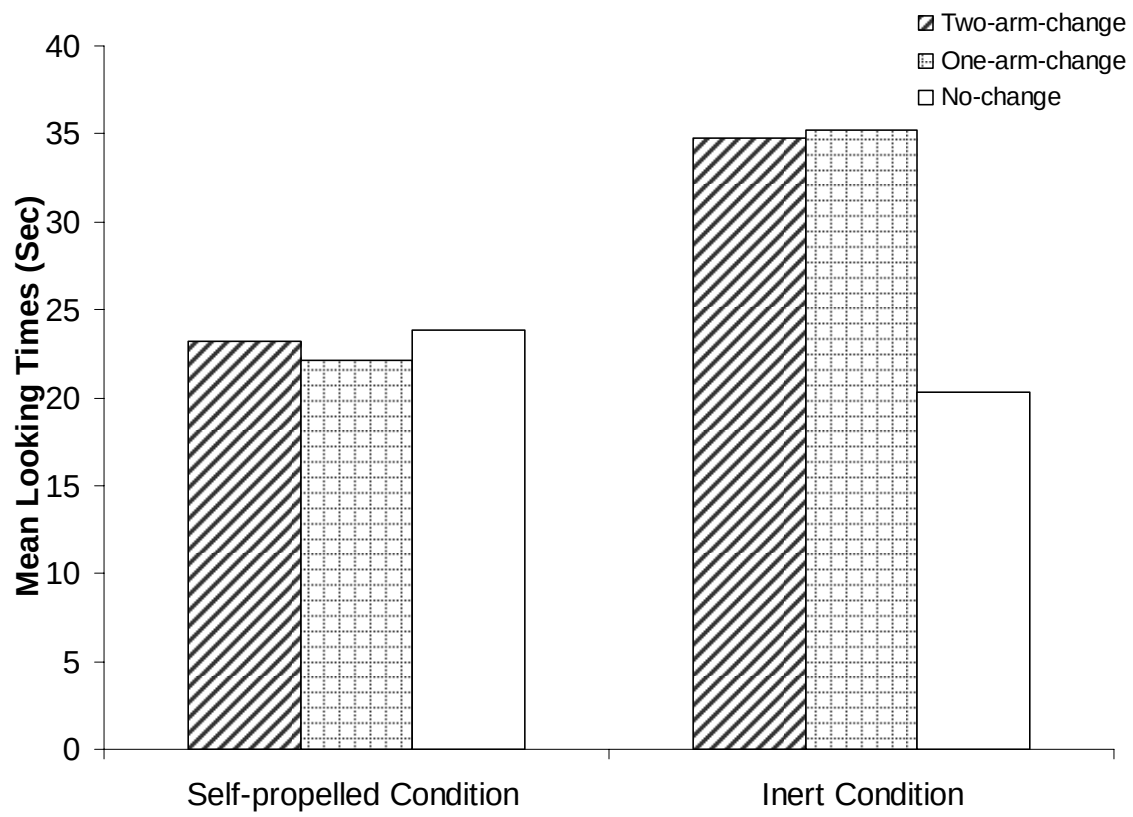
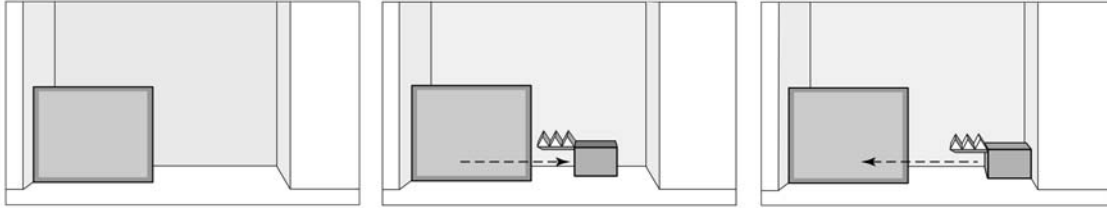


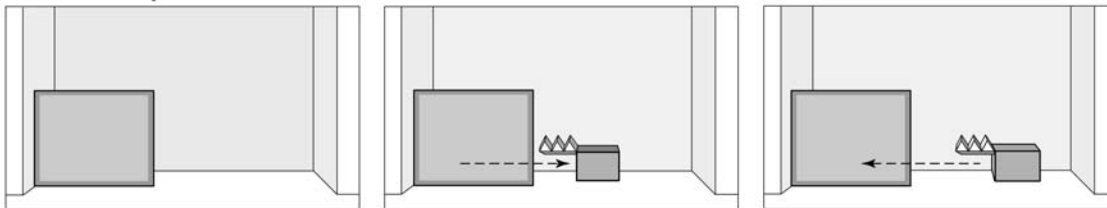
Figure 10. Schematic drawing of the familiarization and test events used in Experiment 4.

Familiarization Event

Inert Condition

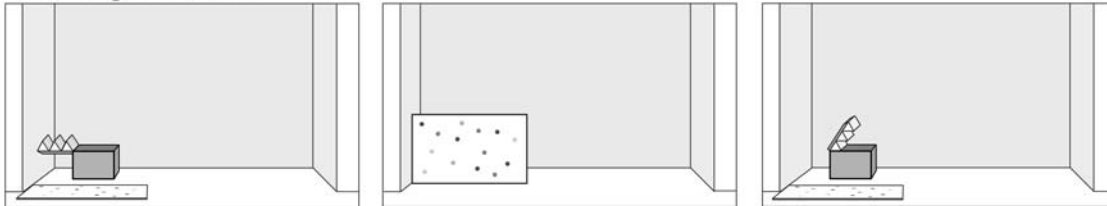


Self-Propelled Condition



Test Events

Change Event



No-change Event

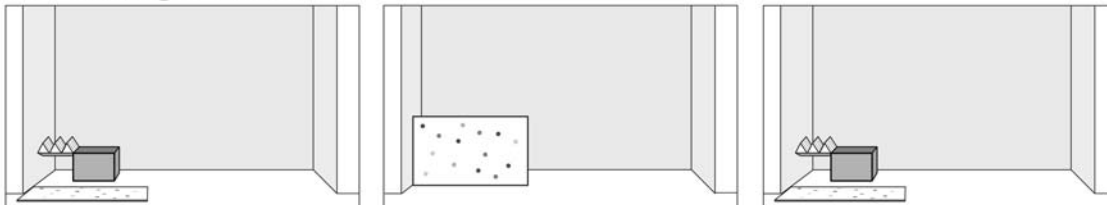


Figure 11. Mean looking times of the test events in Experiment 4.

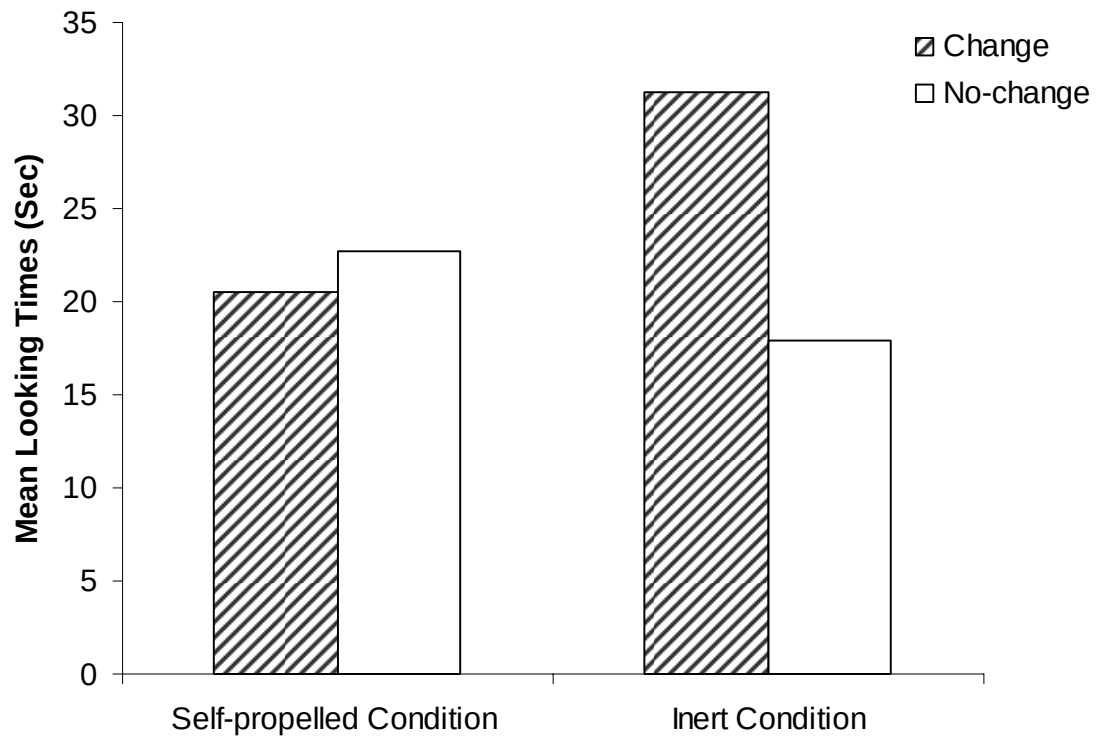
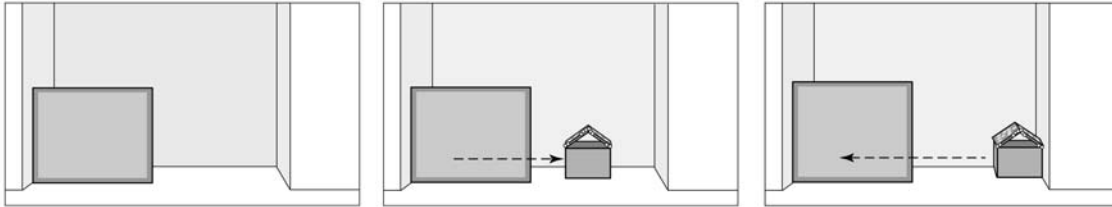


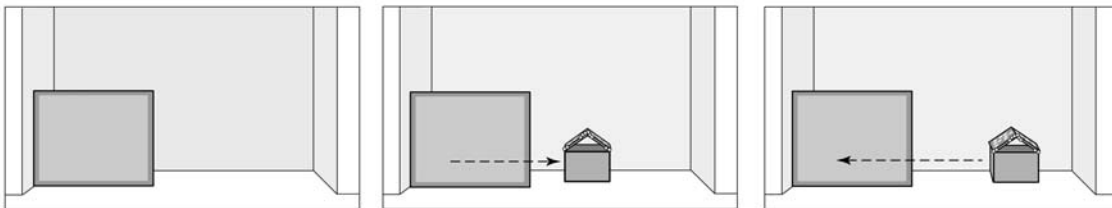
Figure 12. Schematic drawing of the familiarization and test events of the further results in Experiment 4A.

Familiarization Event

Inert Condition

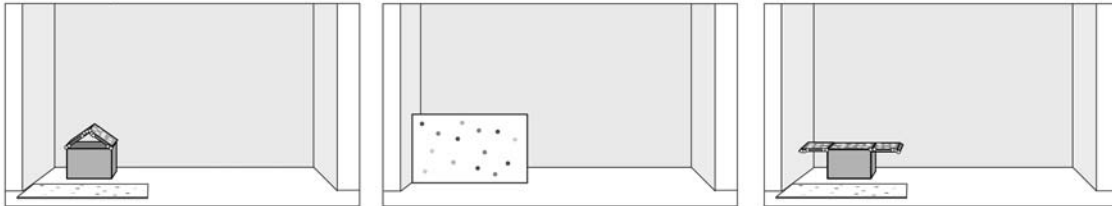


Self-propelled Condition



Test Events

Change Event



No-change Event

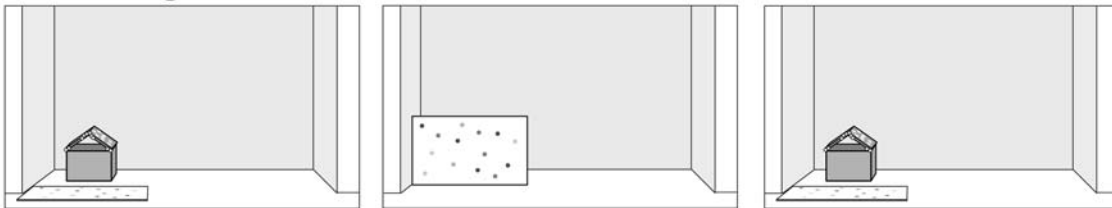


Figure 13. Mean looking times of the test events of the further results in Experiment 4A.

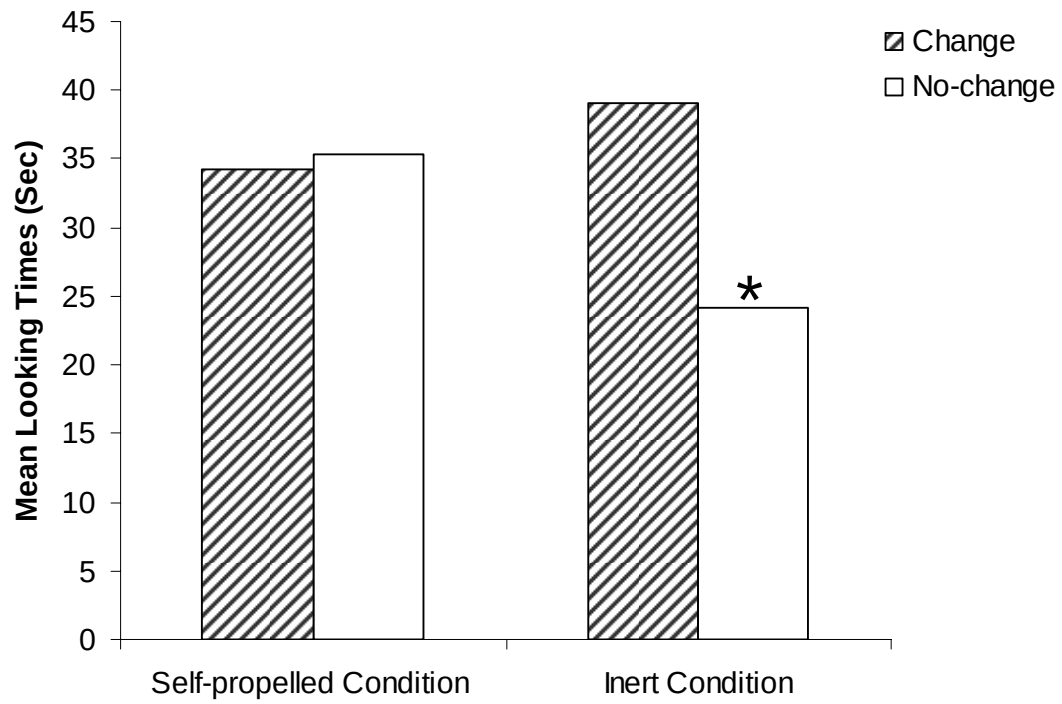


Figure14. Schematic drawing of the orientation, conversation, familiarization, and test events used in the two- and one-toy conditions of Experiment 5.

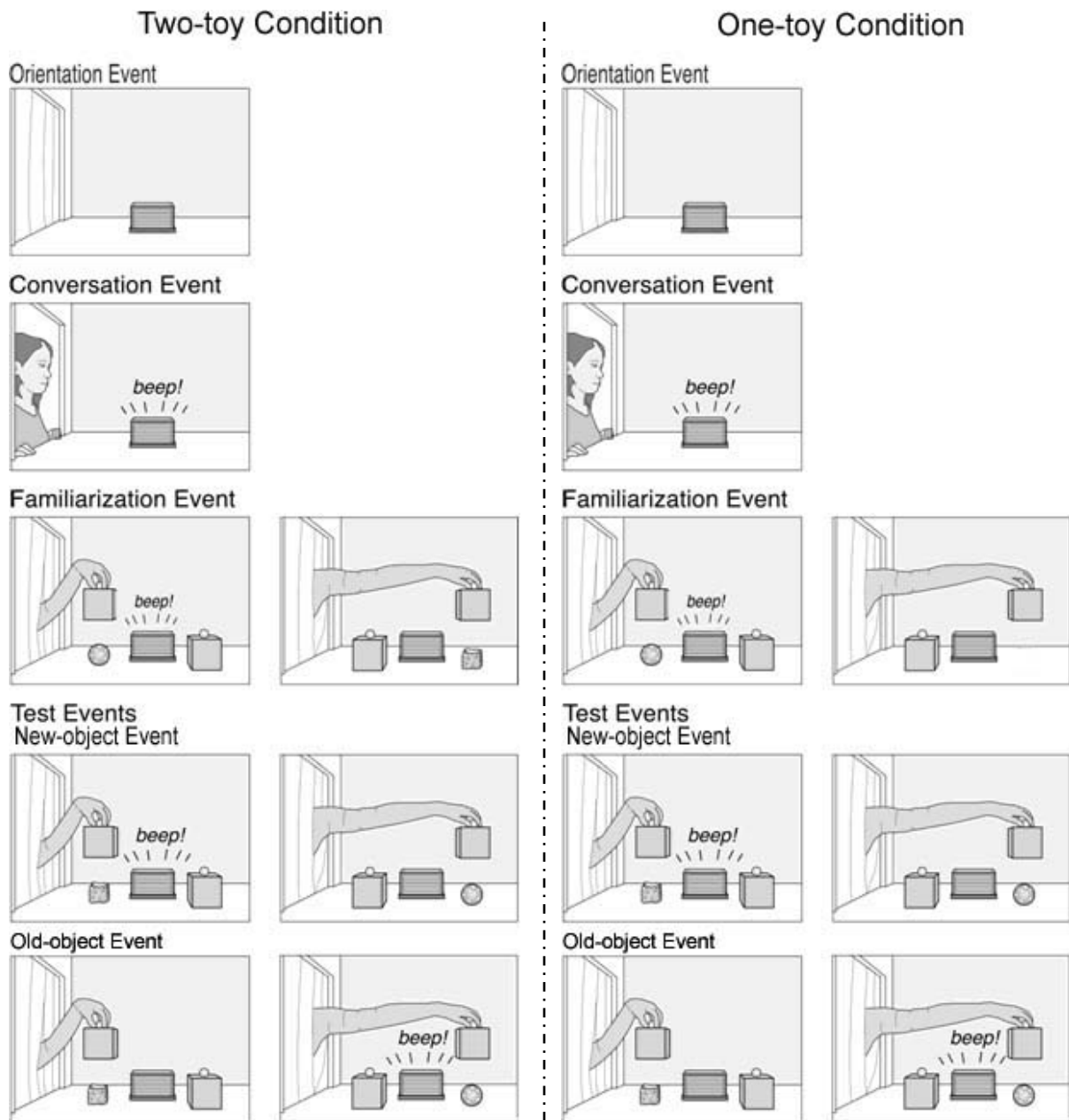


Figure 15. Mean looking times of the test events in the two- and one-toy conditions of Experiment 5.

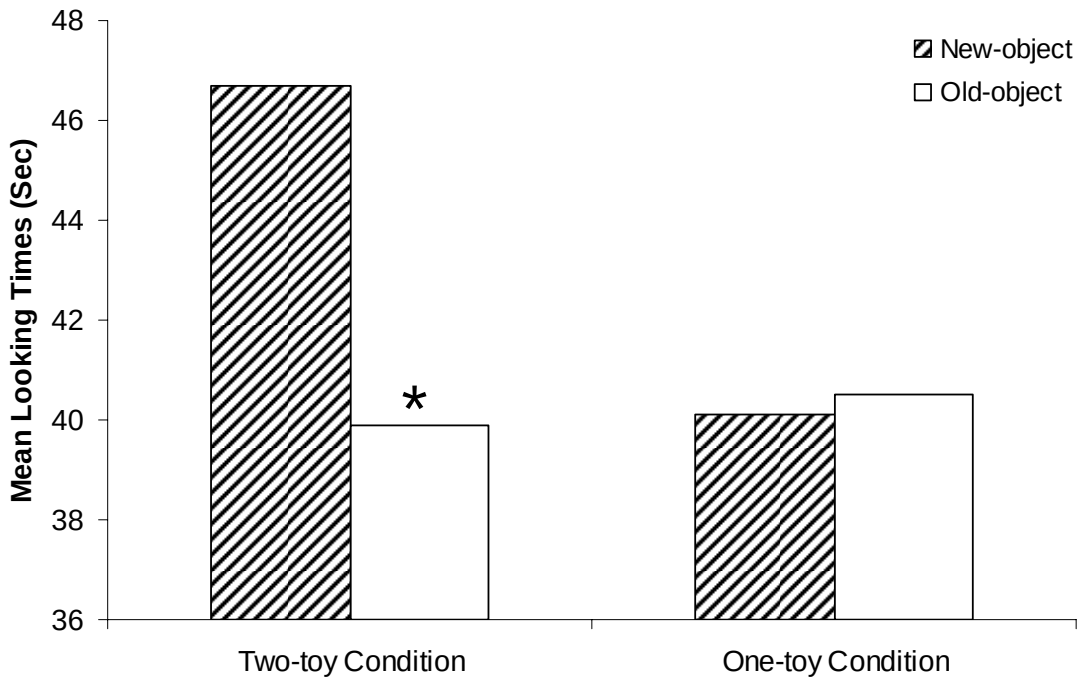


Figure 16. Schematic drawing of the orientation, conversation, familiarization, display, and test events used in the inert and self-propelled conditions of Experiment 6.

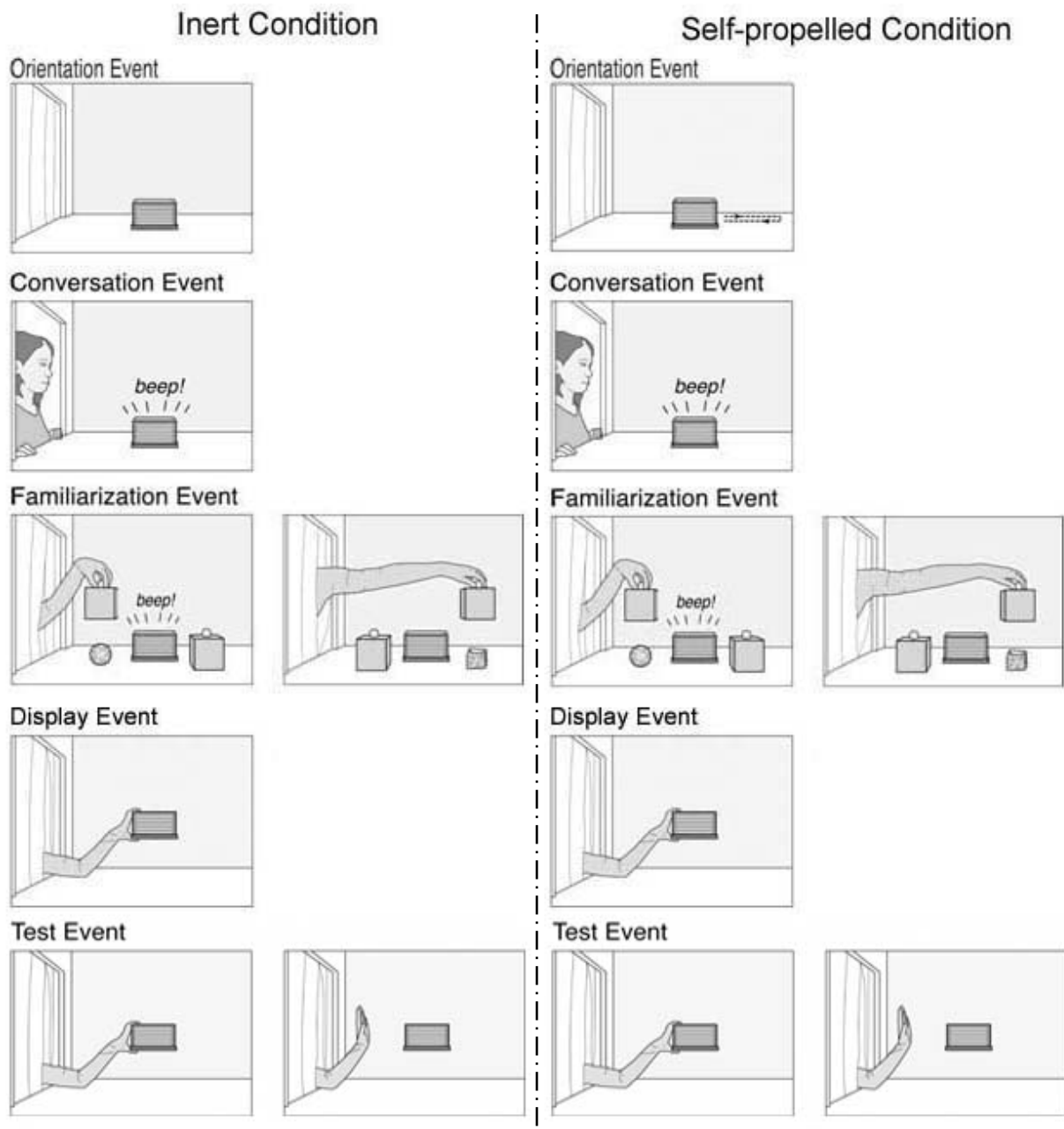


Figure 17. Mean looking times of the display and test events in Experiment 6.

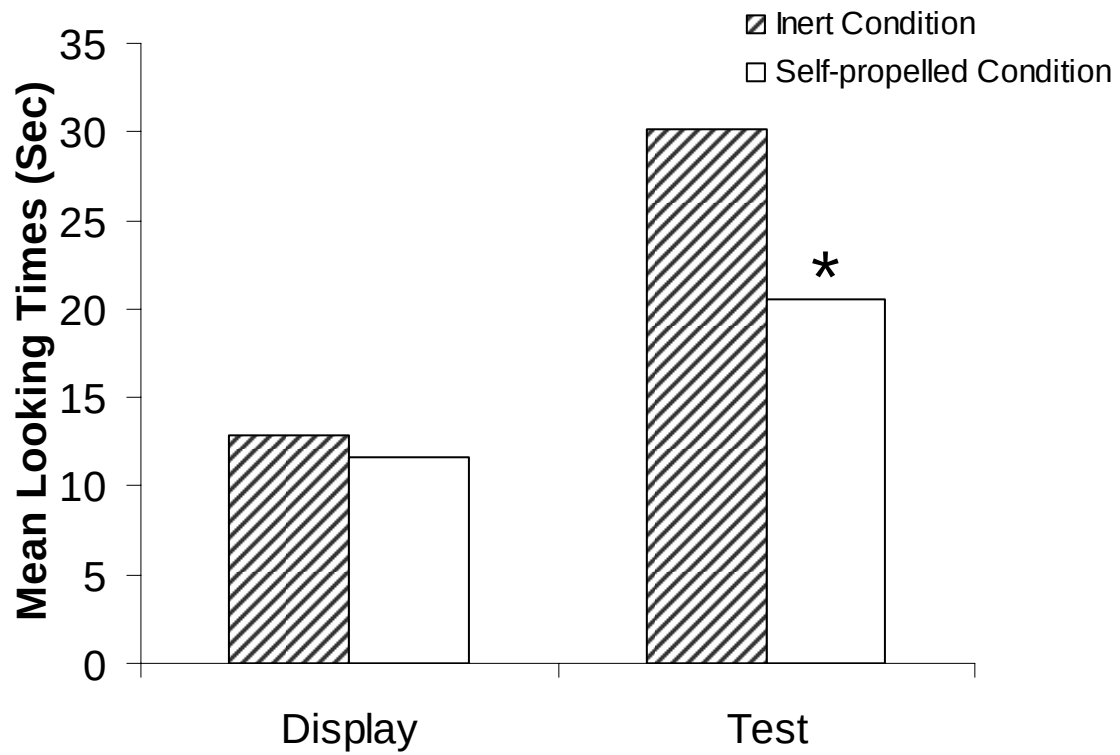


Figure 18. Schematic drawing of the orientation, conversation, display, and test events used in the inert and self-propelled conditions of the further results in Experiment 6.

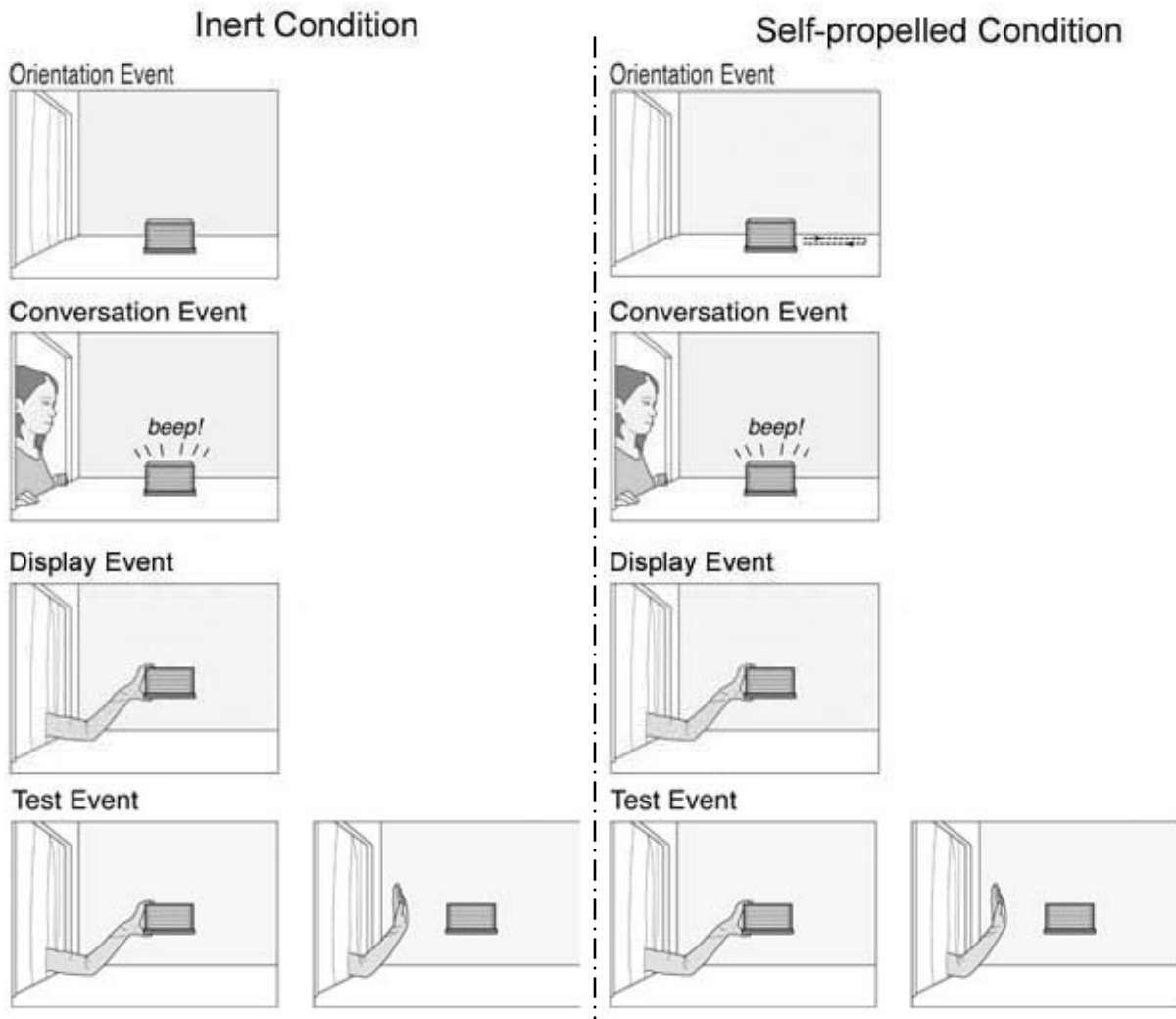


Figure 19. Mean looking times of the display and test events of the further results in Experiment 6.

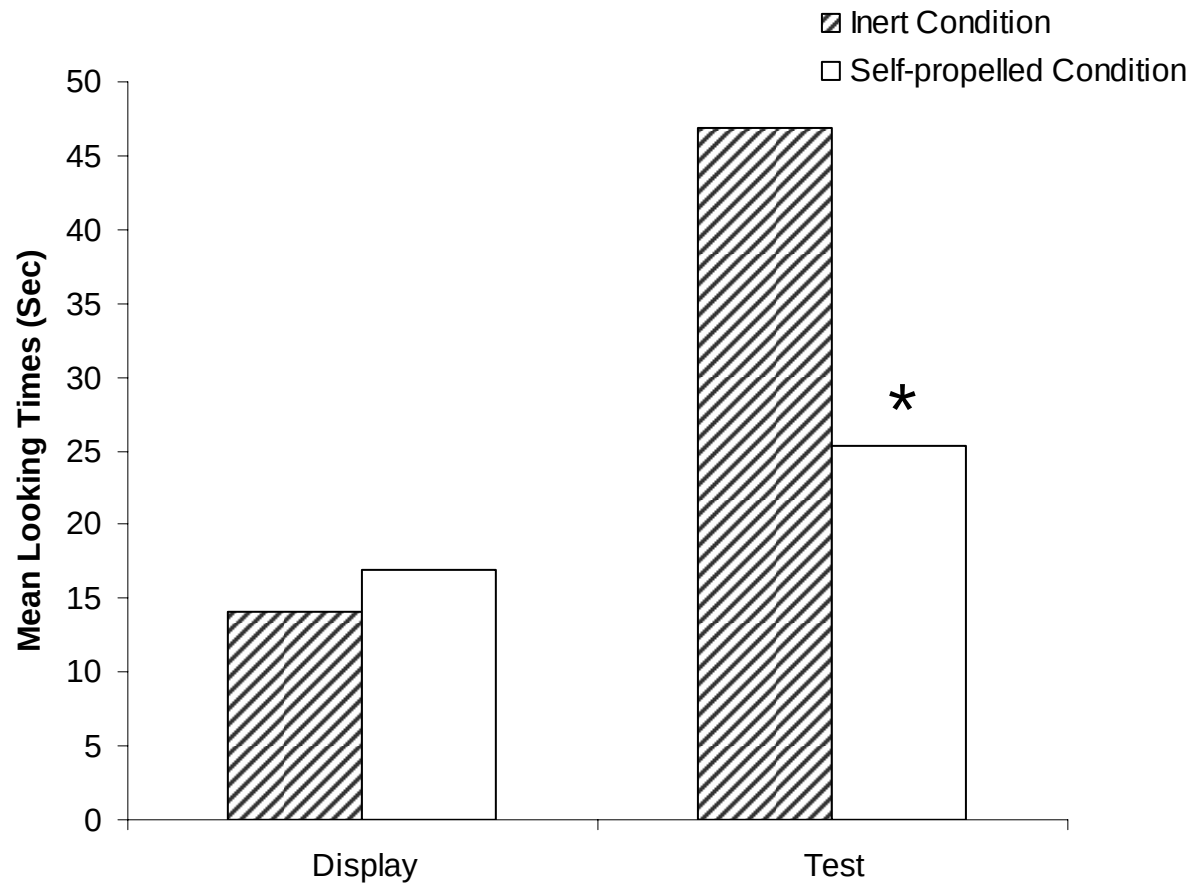
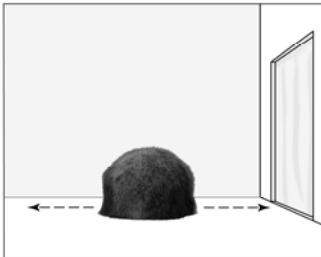


Figure 20. Schematic drawing of the familiarization and test events used in the self-propelled/rattling condition of Experiment 7.

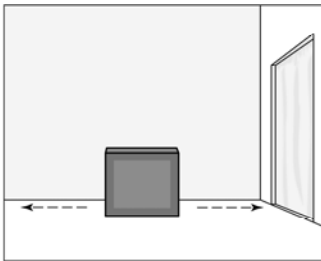
Self-propelled/Rattling Condition

Familiarization Events

Furry-Dome Event

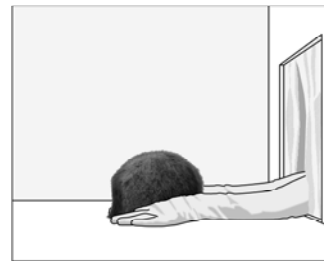
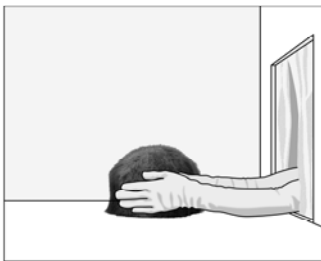


Smooth-Cube Event



Test Events

Furry-Dome Event



Smooth-Cube Event

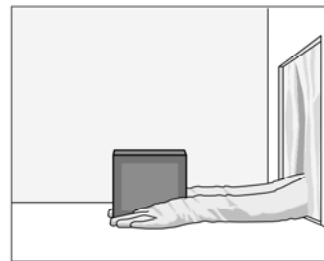
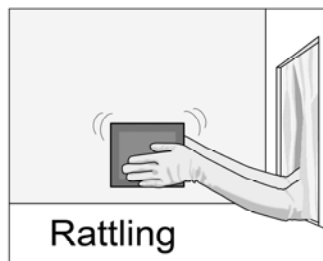
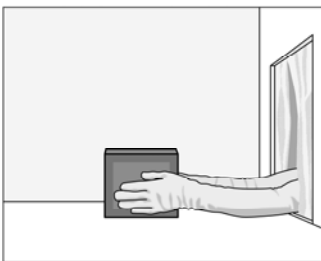
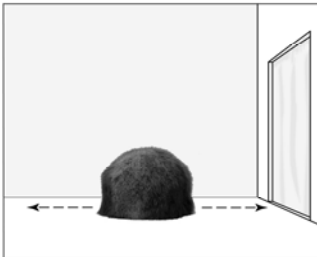


Figure 21. Schematic drawing of the familiarization and test events used in the self-propelled/silent condition of Experiment 7.

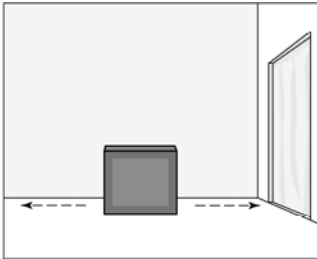
Self-propelled/Silent Condition

Familiarization Events

Furry-Dome Event

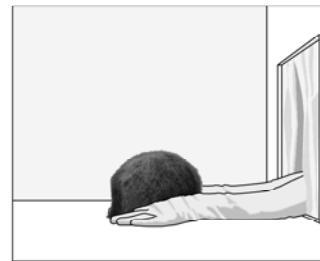
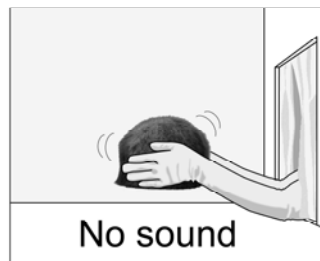
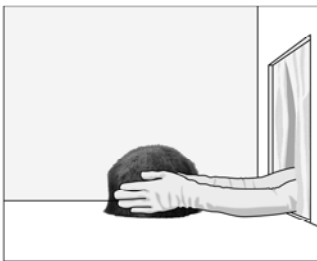


Smooth-Cube Event



Test Events

Furry-Dome Event



Smooth-Cube Event

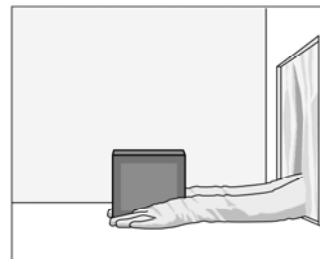
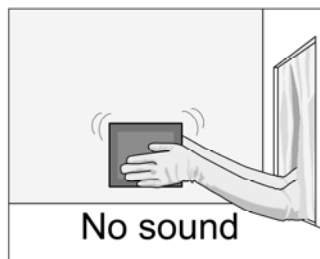
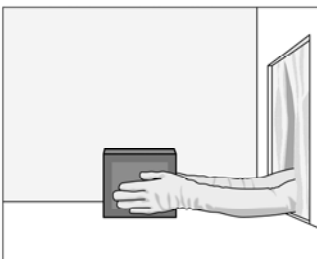
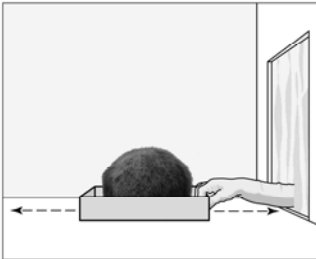


Figure 22. Schematic drawing of the familiarization and test events used in the inert/rattling condition of Experiment 7.

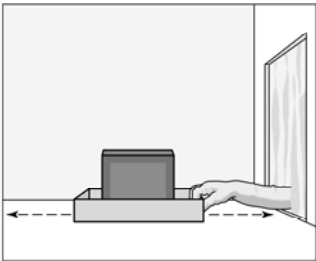
Inert/Rattling Condition

Familiarization Events

Furry-Dome Event

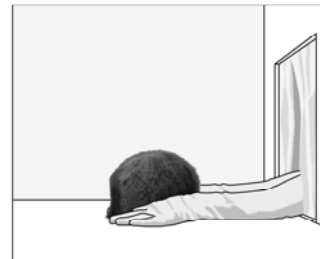
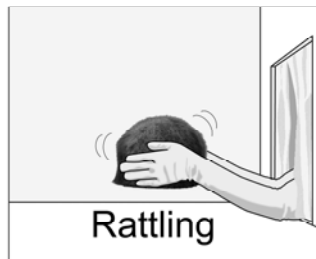
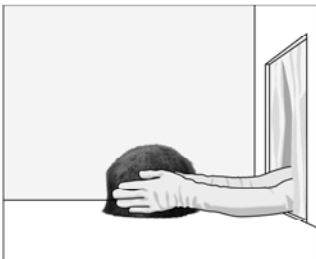


Smooth-Cube Event



Test Events

Furry-Dome Event



Smooth-Cube Event

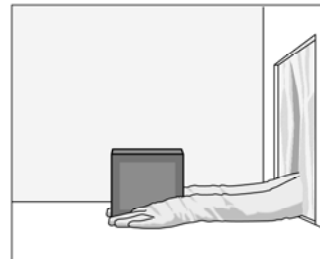
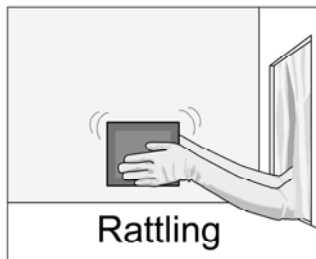
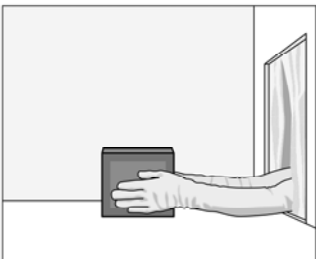
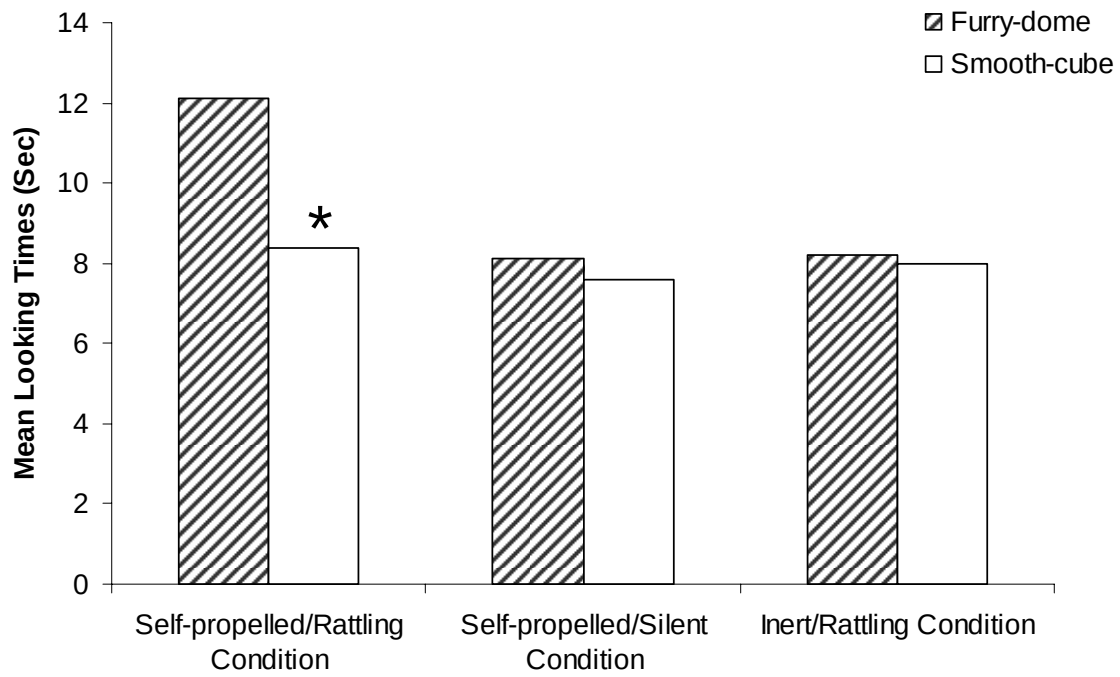


Figure 23. Mean looking times of the test events in the three conditions of Experiment 7.



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