Developmental Psychology
2006, Vol. 42, No. 5, 900–912

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0012-1649/06/$12.00 DOI: 10.1037/0012-1649.42.5.900

Make the First Move: How Infants Learn About Self-Propelled Objects

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In 3 experiments, the author investigated 16- to 20-month-old infants' attention to dynamic and static parts in learning about self-propelled objects. In Experiment 1, infants were habituated to simple noncausal events in which a geometric figure with a single moving part started to move without physical contact from an identical geometric figure that possessed a single static part. Infants were then tested with an event in which the parts of the objects were switched. In Experiments 2 and 3, infants were habituated and tested with identical events except that the part possessed by each object during habitation was switched relative to the first experiment. Results of the experiments revealed that 16-month-olds failed to encode the relation between an object's part and its onset of motion, 18-month-olds were unconstrained in the relations involving self-propulsion that they would encode, and 20-month-olds were constrained in the relations they would encode. The results are discussed with regard to the developmental trajectory of learning about motion properties and the mechanism involved in early concept acquisition.

Keywords: infant, cognition, self-propulsion, animacy, learning

One of the most important and challenging cognitive accomplishments of early childhood is the development of a concept of animacy. This demarcation between animates (i.e., people, animals, and insect) and inanimates (e.g., vehicles, furniture, plants, and tools) represents probably the broadest level at which objects in the world can be grouped and as such is one of the cornerstones of conceptual knowledge. According to a number of recent theoretical views, one of the essential building blocks for these concepts involves learning about the various motion properties of things in the world (e.g., Gelman, 1990; Leslie, 1995; Mandler, 1992; Premack, 1990; Rakison & Poulin-Dubois, 2002). That is, different object kinds move in distinct ways and play distinct roles in motion-related events. Among other things, animates such as animals and people tend to be the cause of an action and move on nonlinear paths, whereas inanimates such as plants and tools tend to be the recipient of an action and move on linear paths.

Although this information is available, albeit intermittently, in the visual input, the perception of these and other motion properties can be misleading (Gelman, Durgin, & Kaufman, 1995); for example, animals can be recipients of an action and move on linear paths, and cars can appear to act as agents and move on nonlinear paths. Perhaps the least ambiguous of all the motion characteristics displayed by different object kinds is that of self-propulsion or *onset of motion*, because only animals and people tend to move without some external physical cause (Premack, 1990; Rakison & Poulin-Dubois, 2001). Despite the potential importance of this cue in delineating different object kinds, there is a dearth of empirical evidence concerning when and how infants learn which things in the world are self-propelled and which are not. My goal in the experiments reported here was to examine the developmental trajectory for this knowledge acquisition and to investigate the mechanism that supports it.

One of the first experiments to examine infants' knowledge of the identity of self-propelled entities was performed by Golinkoff and Harding (1980; cited in Golinkoff, Harding, Carlson, & Sexton, 1984; see also Golinkoff & Kerr, 1978, for related work on agency). Infants at 16 and 24 months of age were presented with events in which a chair started to move without an external cause and their emotional response was measured. The results showed that 24-month-olds but not 16-month-olds showed a negative emotional response to the event, which led the authors to conclude that only by the end of the second year of life do infants understand that inanimate objects are not self-propelled. Poulin-Dubois, Lepage, and Ferland (1996) applied a similar rationale when examining infants' emotional response to typical and atypical events involving self-propulsion. They found that infants at 9 and 12 months of age showed no increase in negative affect when a female stranger started to move (relative to a control condition in which the stimuli were stationary), but they did show an increase in negative affect when a robot started to move. It is worth noting, however, that infants may have responded with negative affect if they had observed any novel object or entity that started to move without any external cause.

More recent evidence that infants are sensitive to self-propulsion but not necessarily about how and when they learn which things in the world tend to be self-propelled was found in a set of studies by Markson and Spelke (2006). In their experimental task, infants at 7 months of age were shown events in which one wind-up toy animal moved on its own and a second wind-up toy animal was moved by a human hand, which were followed by a test phase in which both toys were static on a stage. The results

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This research was partly funded by a Berkman Faculty Development Grant from Carnegie Mellon University. I am grateful to Jessica Cicchino, Jaime Derringer, Jen Fillo, Cheryl Gering, Leah Russell, Mollie Salpeter, and Rachel Wu for help with data collection, participant recruitment, and stimulus preparation.

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showed that infants looked longer at the object that had moved on its own than at the object that was moved by the hand, which the authors interpreted to mean that they had learned that the former was capable of self-propulsion. Infants in a subsequent study, however, looked equally long at the two stimuli when they did not possess animate features (e.g., faces, body parts) or biological, jointed motions (e.g., moving legs). This finding could mean that knowledge about the features usually possessed by self-propelled entities is in place in the first year of life or, alternatively, that such features facilitated infants' processing of the objects by increasing attention to them.

This handful of studies suggest that infants may be sensitive to the perception of self-propulsion early in life but do not learn which object kinds are self-propelled until some point the second year. At the same time, the available evidence provides little insight into the developmental trajectory of this knowledge acquisition or the learning mechanism involved; that is, the work conducted thus far does not delineate how infants learn that some objects are self-propelled and that some are not or that some features typically are possessed by self-propelled objects. In the current set of experiments, I examined this issue by adopting a theoretical approach that stresses the role of *constrained attentional associative learning* in the formation of concepts that include information about the static and dynamic features of objects and entities (Rakison, 2004, 2005; Rakison & Poulin-Dubois, 2001, 2002; see also Quinn & Eimas, 1997; Smith, Colunga, & Yoshida, 2003). According to this view, infants learn about the various motion properties of different object kinds by associating those properties (e.g., agency) with specific causally related functional parts (e.g., legs, hands).

How might infants learn about self-propelled objects through such a process? As stated earlier, a probabilistic relationship exists between animacy and onset of motion such that animates tend to be self-propelled and inanimates (except for rare exceptions such as remote-control objects or those that are moved by the wind) move only after obvious external contact from another object. Furthermore, when objects engage in self-propelled motion, they tend to have specific parts—legs in the case of mammals—that start to move concomitantly. A perceptual system that is inherently biased to attend to dynamic local (legs) and global (self-propulsion) cues and an associative mechanism that encodes relations between these cues will therefore facilitate the development of object concepts that incorporate self-propulsion. In other words, infants may learn over time that there are statistical regularities between the kinds of features possessed by objects and whether they move without external cause. Clearly, there are features other than dynamic parts that are typically possessed by things that exhibit self-propulsion. For example, people and other land mammals have eyes, mouths, and a similar structure with a central trunk and four appendages. The claim here, however, is that the heightened salience of dynamic object features means that infants will associate such features with the specific global motion to which they probabilistically related. Thus, the opening and closing of humans hands would be associated with grasping or goal-directed action, and the movement of legs would be associated with self-propulsion and agency, among other things. Later in developmental time, infants would start to generalize the relations about objects' movement they have learned to other features—eyes, for example—that those objects possess.

Empirical evidence to support this perspective, at least with regard to infants' developing knowledge about the role that objects play in a causal event—namely, whether they are agents or recipients—was found in a series of studies with the habituation paradigm (Rakison, 2005). As with self-propulsion, there are statistical regularities about the kinds of parts possessed by objects and whether those objects tend to be the agents or recipients of an action: Agents tend to have dynamic, moving parts such as legs, arms, hands, and eyes, and recipients tend to have static, nonmoving parts. In an experiment designed to test whether infants are sensitive to these regularities, 12-, 14- and 16-month-olds were presented with simple Michotte-like causal events similar to those used by Leslie and Keeble (1987) and Oakes and Cohen (1990; Cohen & Oakes, 1993). The two stimuli in the events were identical hexagonal geometric shapes with a triangular part on their upper surface. Infants in different experiments were habituated to events in which an object with a dynamic or a static part acted as an agent or as a recipient and then were tested with a familiar event and an event in which the part–causal role relation was switched. For example, if infants were habituated with an event in which an object with a dynamic part caused an object with a static part to move, they were tested with a novel event in which an object with a static part caused an object with a dynamic part to move. The results of the experiments revealed that 12-month-olds learned neither that agents possess dynamic parts and recipients possess static parts nor that agents possess static parts and recipients possess dynamic parts. In contrast, 14-month-olds learned that agents or recipients can possess dynamic or static parts; that is, they were unconstrained in the relations between the parts and causal role that they would encode. Finally, 16-month-olds encoded only those relations that are more commonly observed or that make more sense in the real world, that is, when the agent possessed a dynamic part and the recipient possessed a static part.

These data support the idea that the relation between an object part and a motion property—in this case, the causal role—is sufficient for infants to learn which things act as agents and which things act as recipients in a causal event. In other words, infants may learn that agents of an action tend to possess dynamic parts and recipients of an action tend to possess static parts, and these relations may give rise to expectations about the features possessed by novel agents and recipients and the motion characteristics of novel objects with dynamic or static parts. The findings also imply that associations learned in infancy may constrain the relations that will be learned in the future. That is, infants initially do not encode specific correlations among dynamic and static cues; later on they encode all correlations to which they are exposed; finally, they encode only those correlations that are consistent with their prior experiences. This developmental trajectory has been shown in a number of studies across a wide range of developmental phenomena, which suggests that the same underlying mechanism may account for learning in a number of domains. For instance, Madole and Cohen (1995) found that 14-month-olds will learn relations between form and function that do not make sense in the real world (e.g., when the form of a part predicts the function of another part), whereas 18-month-olds will learn only those correlations that make sense in the real world. Likewise, Stager and Werker (1997) showed that 9-month-olds, who have little word-learning experience, use fine phonetic detail in a syllable discrimination task but that 14-month-olds, who have had greater exposure to their native language, do not.

With these issues in mind, I present the goals of the experiments here, which were twofold. A first goal was to investigate whether infants are sensitive to the relation between a dynamic part and whether an object moves without external contact. If infants encode this relation, then it is plausible that a similar process operates in the real world; that is, infants may learn that self-propelled objects tend to have dynamic parts and that objects that move only after external contact tend to possess static parts. This relationship between dynamic parts and self-propulsion is probabilistic in that it is not always the case that things with moving parts are self-propelled; nonetheless, sensitivity to the strong regularity between dynamic parts and self-propulsion could facilitate infants' ability to form representations for objects that encapsulate their appearance and how they start to move. Note that evidence from the current experiments that supports this idea would indicate only that learning such relations is sufficient for infants to acquire knowledge about the identity of objects that exhibit different motion properties. That is, it could be that infants learn about the identity of self-propelled entities on the basis of associative processes, or it could be that other more specialized processes are involved (see, e.g., Gelman, 1990; Leslie, 1995; Mandler, 1992; Premack, 1990).

My second goal in the experiments reported here was to explore whether infants undergo the same developmental trajectory reported in previous work across a range of domains (e.g., language, gesture, agency, and recipiency) when they learn the relation between dynamic parts and self-propulsion (e.g., Namy, Campbell, & Tomasello, 2004; Rakison, 2005; Stager & Werker, 1997). That is, the experiments were designed to examine whether infants initially fail to encode any part relations involving self-propulsion, then encode all relations to which they are exposed, and then later become constrained in the relations that they will encode. That the same pattern has been found across a wide range of developmental phenomena suggests that the same general mechanism may be responsible for learning in these domains. However, before such a claim can be made, it is important to verify that the developmental trajectory found by Rakison (2005) was not idiosyncratic to early learning about the features typically possessed by agents and recipients in a causal event.

To examine these issues, I ran experiments that used the same kinds of Michotte-like events used in Rakison (2005). However, instead of infants being habituated to causal events, they were presented with noncausal events in which one object moved across a screen and stopped before contacting an identical object, which then moved away after a short delay. The rationale for this design was that the second object was not made to move by the first object and, therefore, its onset of motion must have been self-initiated. In contrast, because the first object moved from offscreen, its onset of motion was ambiguous. During the test phase, infants were presented with the same events, but the part-onset of motion relation was switched. As in previous work on infants' ability to learn about motion properties (e.g., Rakison, 2004; Rakison & Poulin-Dubois, 2002), geometric figures were used rather than real-world objects, because my aim in these experiments was to investigate the mechanism underlying learning rather than prior knowledge about specific objects and whether they are self-propelled (e.g., animals, people).

Experiment 1

In this experiment, I used a cross-sectional design to examine 16- and 20-month-old infants' ability to associate self-propulsion with a dynamic part. Infants were habituated to noncausal events in which an object with a static part moved across a screen (its onset of motion was ambiguous because it started moving at a point off the screen) and stopped before contacting an identical object. After a short delay, the second object started to move across the screen away from the first object and, as it did, its part also moved. During the test phase, infants were shown two noncausal test events and two causal test events, with the noncausal test events always preceding the causal test events. One of the noncausal test events was identical to that seen during habituation. The other noncausal test event involved a switch in the relation between onset of motion and the part the object possessed; that is, the first object possessed a dynamic part and the second object possessed a static part. Two posttest causal events helped to determine whether infants perceived the habituation events as noncausal as well as whether longer looking to the switch test trial resulted solely from infants attending to which part type the object that initially appeared on the screen possessed.

Method

Participants. The participants were 16 healthy full-term infants at 16 months of age (mean age 16 months 4 days; range = 15 months 15 days to 16 months 14 days) and 16 healthy full-term infants at 20 months of age (mean age 20 months 5 days; range = 19 months 17 days to 20 months 12 days). There were an equal number of boys and girls in both age groups. The majority of infants were White and of middle socioeconomic status. Data from 12 other infants were excluded from the final sample, 6 because of failure to habituate (three 16-month-olds and three 20-month-olds), 4 because of fussing or crying (2 in each age group), and 2 because of experimenter error. Infants were recruited through birth lists obtained from a private company and were given a small gift for their participation.

Stimuli. The habituation and test stimuli were computer-animated events created with Macromedia Director 8.0 for PC and were identical to those used by Rakison (2005). In each noncausal event, a geometric figure that was initially out of sight and offscreen moved horizontally across a screen for 280 pixels and stopped before making contact with a second geometric figure that was situated in the center of the screen (the distance between the objects was 35 pixels). Note that because the first figure started moving offscreen, it was ambiguous whether this object was self-propelled or caused to move. After a short delay (1 s), the second figure began to move at the same speed and in the same direction as the first object and continued to do so until offscreen (a distance of 320 pixels). Each event lasted 8.0 s and could be repeated up to three times per habituation or test trial. Individual presentations of each event were divided by a blue screen that descended and ascended over 2 s. The geometric figures in the events were hexagonal red shapes with a green triangular part situated on their top. The figures were 124 pixels tall and 136 pixels wide. Each figure also possessed a yellow internal star shape to increase their interest to infants. The figures are shown in Figure 1A and 1B. During the event, the triangular part of one of the figures moved horizontally back and forth by 65 pixels as the object moved and the triangular part of the other figure was static.

For the habituation trials, events were created in which the first object possessed a static part and the second object possessed a dynamic part. The dynamic part moved only when the object to which it was attached moved across the screen; that is, the movement of the part was correlated with self-propulsion. There were two habituation events, one in which the objects moved from left to right and one in which the objects moved from

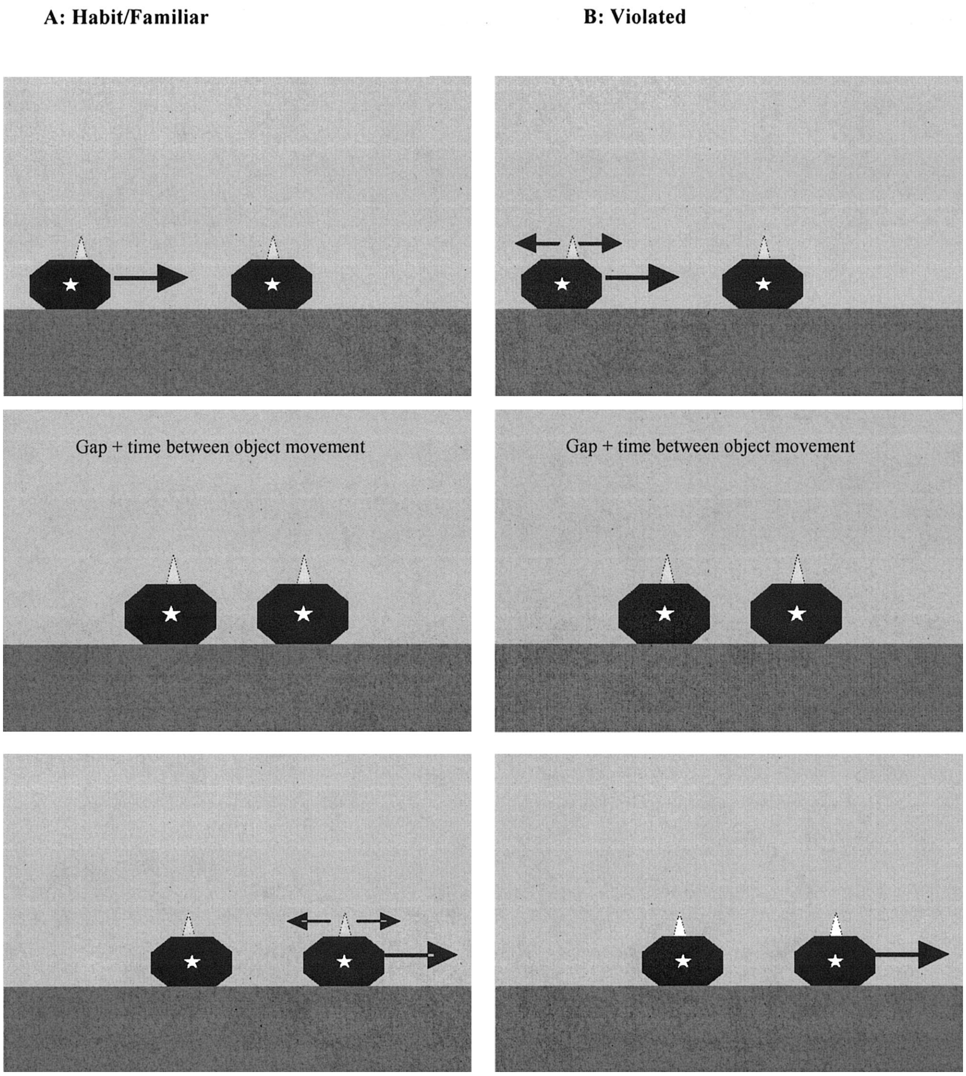

Figure 1. Example of stimulus events in Experiment 1.

right to left. Figure 1A shows an instance of a noncausal event presented during the habituation phase and as the familiar test event. It can be seen that the first object on the screen possessed a static dynamic part and the second object possessed a dynamic part. An additional pair of events (one in which the objects moved from left to right and one in which the objects moved from right to left) was produced in which the first object possessed a dynamic part and the second object possessed a static part (see Figure 1B).

Four direct causal events were created for two posttest control trials. The events involved the same geometric figures as those presented during the habituation phase, but the first object contacted the second object, which then moved immediately in the same direction. In two events (one in which the objects moved from left to right and the other in which the objects moved from right to left), the first object possessed a dynamic part and the second object possessed a static part. In the other two events (again, one in which the objects moved from left to right and the other in which the objects moved from right to left), the first object possessed a static part and the second object possessed a dynamic part. Each event lasted 8 s and individual presentations were separated by the same blue ascending and descending screen (of 2-s duration) presented during habituation. The rationale for the two posttest causal events was twofold. First, they helped to evaluate whether longer looking to the novel switch test trial was caused only by infants' attention to the first object that appeared on the screen. That is, if infants' relatively long looking at the switch test trial was because an object with a dynamic part appeared first on the screen (instead of because of the part-onset of motion relation), the infants would be expected also to look longer at the posttest trial in which an object with a dynamic part moved first onto the screen. Second, by comparing looking times with the familiar noncausal event and the first posttest causal event, it was possible to determine whether infants perceived the habitation events as noncausal. If infants did not perceive these events in such a way, it would be impossible to draw conclusions about their perception of the second object as moving without an external cause.

Design. The two noncausal events in which the first object possessed the static part and the second object possessed a dynamic part were used as habituation stimuli. After habituation, infants were presented with two noncausal test events and two posttest causal test events. The *familiar noncausal* event was identical to one of those observed during the habituation phase. The *switch noncausal* event was the same as the habitation events, except that the first object on the screen possessed a dynamic part and the second object possessed a static part. The *familiar causal* event was the same as the habituation events in terms of the kind of part possessed by each object (the first object possessed a static part and the second object possessed a dynamic part), and the *switch causal* event was the same as the switch noncausal event in terms of the position of the parts (the first object possessed a dynamic part and the second object possessed a static part). The direction in which the objects moved in the test trials (i.e., left to right or right to left) was counterbalanced across the infants in each age group.

Apparatus. Each infant was tested individually in a small, silent, softly lit laboratory room (approximately 3.0 m × 2.5 m). During the testing procedure, events appeared on a 43-cm computer monitor approximately 80 cm from the infant's face. The computer monitor was on a table and was not concealed in any way. A black curtain that spread from the ceiling to the floor was at the rear of the monitor and surrounded the testing chamber. A closed-circuit video camera was located above and behind the monitor and was hidden from view by the black curtain. The video camera allowed an experimenter to monitor and code the infant's looking behavior to the stimuli. The video camera also recorded each infant's visual fixation so that at a later date a second experimenter could determine a reliability score to verify the initial coding. The experiment was controlled by Habit 2000 (Cohen, Atkinson, & Chaput, 2000) on an Apple G4 computer.

An experimenter who was hidden by the curtain observed each infant's visual gaze on a television monitor connected to the video camera. The experimenter coded the duration of a visual fixation by pressing a key on a computer keyboard when the infant looked at the computer monitor and releasing the key when the infant looked away from the monitor. A green expanding and contracting circle on a dark background was presented on the screen to capture the infant's attention before the first trial of the experiment and in between each trial during the experiment. A bell sound was presented in synchrony with the expanding and contracting movement to increase the attractiveness of the event and secure the infant's visual attention. Immediately after the infant fixated on the computer monitor, the experimenter began the next (or first) trial by pressing a predetermined key on the computer keyboard. The computer recorded the length of each keypress and in so doing the visual fixations for each event, and it determined when the habituation phase of the experiment ended and the test phase began.

Procedure. Each infant sat facing the computer monitor on his or her parent's lap. The parent was instructed to remain neutral, not to interact with the infant verbally or otherwise, and to focus his or her gaze above the computer screen. This procedure with parents has been used in previous studies with the habituation procedure (e.g., Rakison, 2004, 2005; Rakison & Poulin-Dubois, 2002), and it is preferable to using a blindfold or sunglasses because the parent can monitor and pacify a potentially fussy infant. Note also that parents were given no information about the hypotheses and predictions of the experiments prior to testing.

Infants were tested with a version of the subject-controlled criterion habituation procedure. As outlined in the *Stimuli* and *Design* sections, during the habituation phase of the experiment, each infant was presented with two noncausal events. The order of the habituation trials was semi-random within each age group, with no event appearing sequentially more than twice and with half of the infants receiving one habituation trial first and the other half receiving the other habituation trial first. An event was presented until the infant looked away from the monitor for over 1 s or until 30 s of uninterrupted looking had elapsed. The habituation phase ended when an infant's looking time decreased to a set criterion level or until 16 trials were presented. An infant's looking time on a block of three successive trials had to be less than 50% of the total looking time measured on the first three trials to reach criterion. Once this criterion was reached or after 16 trials, the test events were automatically presented. Infants who failed to reach criterion within 16 trials were excluded from the final analysis. Every infant was shown the two noncausal test trials before the two causal test trials because the contrast between the two noncausal trials was primary to the experimental hypotheses. The order of the noncausal and causal test trials was counterbalanced across infants.

Coding and analyses. The lengths of the infant's visual fixations were coded by the experimenter's keypresses and recorded by the computer. A second experimenter independently coded videotaped footage of the looking behavior of 25% of the infants (4 in each age group). Interobserver reliability was established in two ways. First, a Pearson product–moment pairwise correlation was computed for the scores coded on the online and the videotaped trials. Second, the mean difference between the main experimenter and the second experimenter for the looking time coded on each trial was examined. Reliability for infants' looking times in the experiments presented here was $r > .95$, and the mean difference between the two coders on each trial was less than 0.25 s.

Results

The principal analysis involved examining infants' looking behavior to the noncausal familiar and noncausal switch test events. In this experiment and the others reported here, sex was excluded as a factor in the analyses because it was found not to effect looking times for the same stimuli in experiments on agency (Rakison, 2005). The visual fixation times were investigated with a mixed design analysis of variance (ANOVA) with test event (switch vs. familiar) as the within-subjects factor and age (16 months vs. 20 months) as the between-subjects factor. The analysis revealed a significant main effect of test event, $F(1, 30) = 4.56$, $p < .05$, and a significant interaction between test event and age, $F(1, 30) = 4.24$, $p < .05$. Figure 2 shows the mean looking times of the two age groups during the two noncausal and two causal test trials. Planned comparisons showed that 16-month-old infants' looking times to the switch ($M = 7.80$ s, $SD = 7.27$ s) and familiar ($M = 7.94$ s, $SD = 7.34$ s) test trials were equivalent, $F(1, 15) = 0.03$, $p > .8$. In contrast, the 20-month-olds looked significantly longer at the switch ($M = 13.27$ s, $SD = 9.28$ s) than at the familiar ($M = 5.82$ s, $SD = 4.81$ s) test trials, $F(1, 15) = 10.48$, $p < .01$. There was no significant main effect for age, $F(1, 30) = 1.11$, $p > .03$, and no significant interaction between age and the other variables.

In a second set of analyses, I examined infants' visual fixation on the two causal posttest trials. The purpose of including these trials was twofold: First, they made it possible to eliminate the possibility that longer looking to the causal switch event relative to the causal familiar test event was solely because of a response to which object appeared first on-screen (the one with the dynamic or the static part) rather than a violation of object parts and onset of motion relation. That is, if infants' looking behavior in the noncausal test trials was due only to the part possessed by the first stimulus, they would be expected to look longer at the noncausal switch event than the noncausal familiar event. To address this issue, I submitted the visual fixation times for the two posttest trials to 2 (posttest event: switch vs. familiar) × 2 (age: 16 months vs. 20 months) mixed-design ANOVA. The analysis showed that infants in both age groups looked equally long at the two causal events, $F(1, 30) = 0.57$, $p > .5$. There was also no difference in looking times across the two age groups, $F(1, 30) = 0.45$, $p > .5$, and no significant interaction between age and posttest event. Thus infants' looking times to the two noncausal test events were not affected by the object that appeared first on-screen.

The causal posttest trials were also used to establish whether infants perceived the habituation events as noncausal. It is impor-

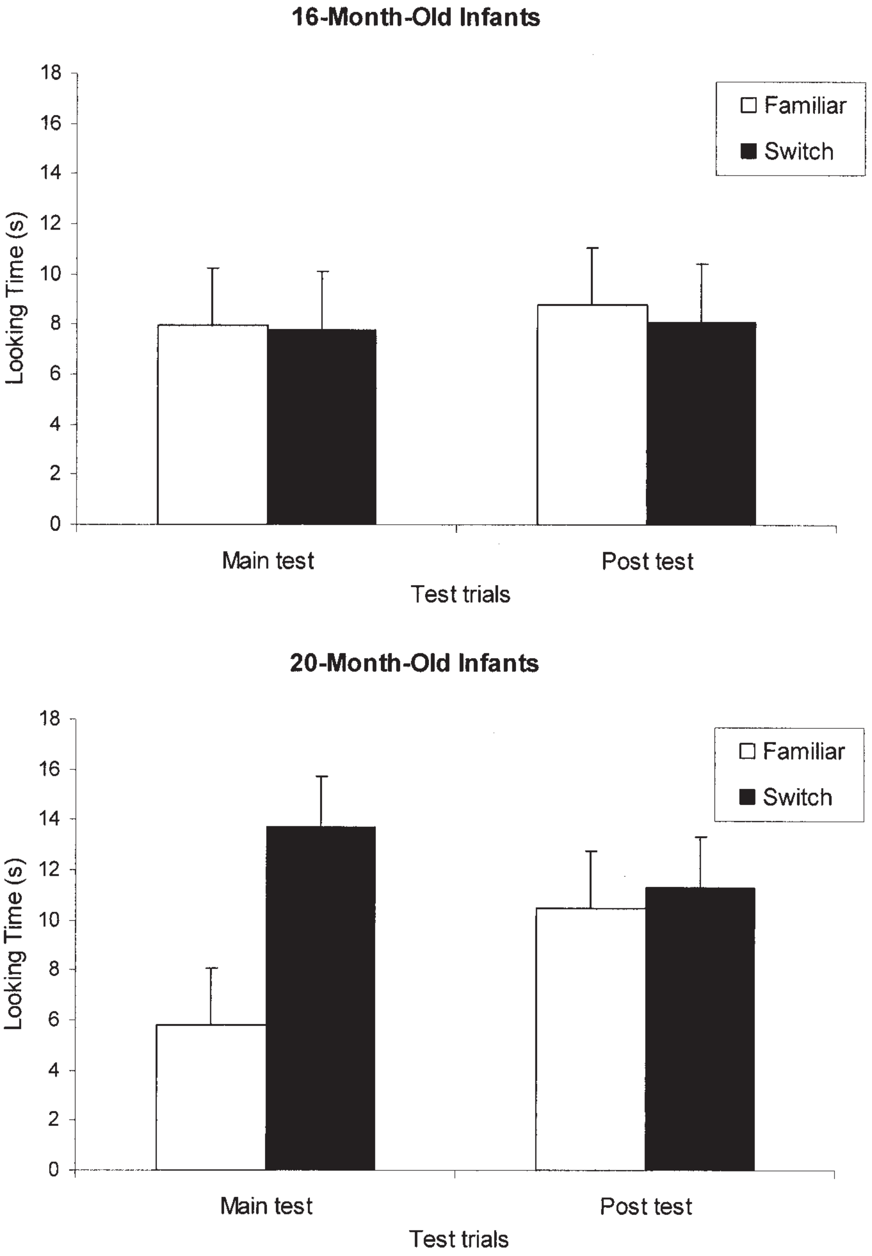

Figure 2. Mean looking times and standard errors (depicted by vertical lines) during the two causal and noncausal test trials for 16- and 20-month-old infants in Experiment 1.

tant to show that this was the case because infants could not interpret the second object's movement as being self-propelled if they perceived the events as causal rather than noncausal. To examine this issue, I compared infants' looking time to the familiar noncausal event with that to the first causal event (see Rakison, 2005). The data were submitted to a 2 (trial type: familiar noncausal test vs. first causal test) × 2 (age: 16 months vs. 20 months) mixed-design ANOVA. The analysis revealed that across the two age groups, infants looked significantly longer at the first causal test trial (16 months: $M = 11.95$ s, $SD = 8.79$ s; 20 months: $M = 13.76$ s, $SD = 10.39$ s) than at the familiar noncausal test trial (16 months: $M = 7.80$ s, $SD = 7.27$ s; 20 months: $M = 5.82$ s, $SD = 4.81$ s), $F(1, 30) = 14.73$, $p < .001$. There were no further significant main effects or interactions. This suggests that infants perceived the habituation events as noncausal and discriminated those events from the causal posttest trials in terms of causality.

Discussion

The results of Experiment 1 revealed that infants at 20 months of age but not those in the younger age group are sensitive to and encode the relation between object parts and onset of motion. That is, 20-month-olds recovered visual attention when the relation between part and onset of motion was violated, whereas 16-month-olds did not. That infants in both age groups looked longer at the causal posttest trials implies that the habituation trials were perceived as noncausal, a corollary of which is that the movement of the second object in those trials was not seen to be caused by the first object. Furthermore, 20-month-old infants' longer looking to the switch test trial relative to the familiar trial did not result from a change in the part that appeared first on the screen.

These data indicate that attention to the statistical relation between a static or dynamic part and different kinds of onset of motion may be sufficient to account for how infants learn which things in the world are self-propelled and which things are not. The finding that infants learned the association in the events over a brief habituation period is particularly impressive because the stimuli were identical in every way other than whether their part was dynamic or static. One possible explanation for the 20-month-olds' behavior is that they had already learned that in the real world, self-propelled objects have dynamic parts. That is, the habituation events may have tapped their existing knowledge about the features possessed by things that start to move without external force. Alternatively, it could be that the 20-month-olds learned online the relations in the event, which would suggest that infants can quickly encode such relations by the middle of the second year of life. To address this issue, in Experiment 2, I presented infants with relations that are generally inconsistent with those in the real world; that is, the second object, which moved without contact from the first object, possessed a static part. If infants at 16 and 20 months of age have little knowledge about the features of self-propelled entities, they would be expected to learn the correlations in the events. In contrast, if infants bring to the laboratory knowledge about the features of self-propelled objects, they would be expected not to encode relations that are incongruent with this knowledge.

Experiment 2

The design of Experiment 2 was identical to that of Experiment 1 with the exception that the first object on-screen possessed a dynamic part and the second object possessed a static part. Note that although the first element of the events—that is, the object with a dynamic part moving on-screen and stopping—was not inconsistent with episodes that infants might observe in the real world, the second element—an object with a static part that moved without external force—was. The rationale for presenting infants with relations that are contradictory with those in the real world was to address whether infants' knowledge of part–motion relations constrains the relations to which they will attend (Rakison, 2005). Madole and Cohen (1995) relied on a similar line of thinking to show that 18-month-old infants, who have experience with form–function correlations in the real world, will learn only those correlations between form and function that make sense. On the basis of these findings and the performance of infants in Experiment 1, it was predicted that infants in both age groups would not learn the relations in the events.

Method

Participants. Sixteen healthy full-term 16-month-olds (mean age 15 months 30 days; range = 15 months 14 days to 16 months 13 days) and sixteen 20-month-olds (mean age 20 months 4 days; range = 19 months 16 days to 20 months, 13 days) were the participants. There were an equal number of boys and girls in both age groups. Data provided by 10 additional infants were not included in the final sample, 7 because of a failure to habituate (four 16-month-olds and three 20-month-olds), 2 because of fussing or crying, and 1 because of experimenter error. Infants were recruited in the same way as in Experiment 1 and were given a small gift for their participation.

Stimuli, design, apparatus, and procedure. The stimuli were the same as those used in Experiment 1, except that during habituation, infants were shown noncausal events in which the first object on-screen possessed a dynamic part and the second object possessed a static part. In the test phase, infants were presented with a familiar noncausal event that was the same as one of the two shown during habituation as well as a switch noncausal event in which the second object possessed a dynamic part and the first object that appeared on-screen possessed a static part. The two posttest causal events were the same as those used in Experiment 1. All other aspects of the apparatus, design, and procedure were identical to those of in Experiment 1.

Results

The primary analyses were used to examine infants' looking times to the familiar and switch test events. The looking times were submitted to a mixed-design ANOVA with test event (switch vs. familiar) as the within-subject factor and age (16 months vs. 20 months) as the between-subjects factor. The analysis showed no significant main effect for test event, $F(1, 30) = 0.23$, $p > .7$, or for age, $F(1, 30) = 2.54$, $p > .1$, and no significant interaction between the two variables. Thus, infants at 16 and 20 months of age looked equally long at the switch event (16 months: $M = 6.28$ s, $SD = 4.34$ s; 20 months: $M = 7.93$ s, $SD = 7.07$ s) and the familiar event (16 months: $M = 5.37$ s, $SD = 4.41$ s; 20 months: $M = 8.34$ s, $SD = 6.39$ s). Figure 3 presents the mean looking times of the two age groups during the two noncausal test trials and the two causal posttest trials.

The second analysis was used to evaluate infants' looking behavior on the two causal test trials. Looking times were analyzed with a 2 (posttest event: switch vs. familiar) × 2 (age: 16 months vs. 20 months) mixed-design ANOVA. The analysis indicated that infants in the two age groups looked equally long at the switch and familiar posttest events, $F(1, 30) = 0.58$, $p > .6$. The analysis also revealed that infants in the two age groups looked for equivalent lengths of time at the events, $F(1, 30) = 1.89$, $p > .1$. There was no significant interaction between the variables.

As in Experiment 1, a further analysis was used to compare infants' visual fixation times at the familiar noncausal event and the first causal event. The data were submitted to a mixed-design ANOVA with trial type (familiar noncausal test vs. first causal test) as the within-subjects factor and age (16 months vs. 20 months) as the between-subjects factor. Consistent with Experiment 1, the analysis revealed that infants in both age groups looked significantly longer at the first causal posttest trial ($M = 12.46$ s, $SD = 7.62$ s) than at the familiar noncausal test trial ($M = 6.86$ s, $SD = 6.39$ s), $F(1, 30) = 9.30$, $p < .005$. There was no significant main effect of age and no significant interaction between age and trial type.

To determine how the habituation stimuli in Experiments 1 and 2 affected infants' behavior, I ran a final analysis to evaluate looking times across the two experiments on the two noncausal test trials. For each age group, looking times were entered into a 2

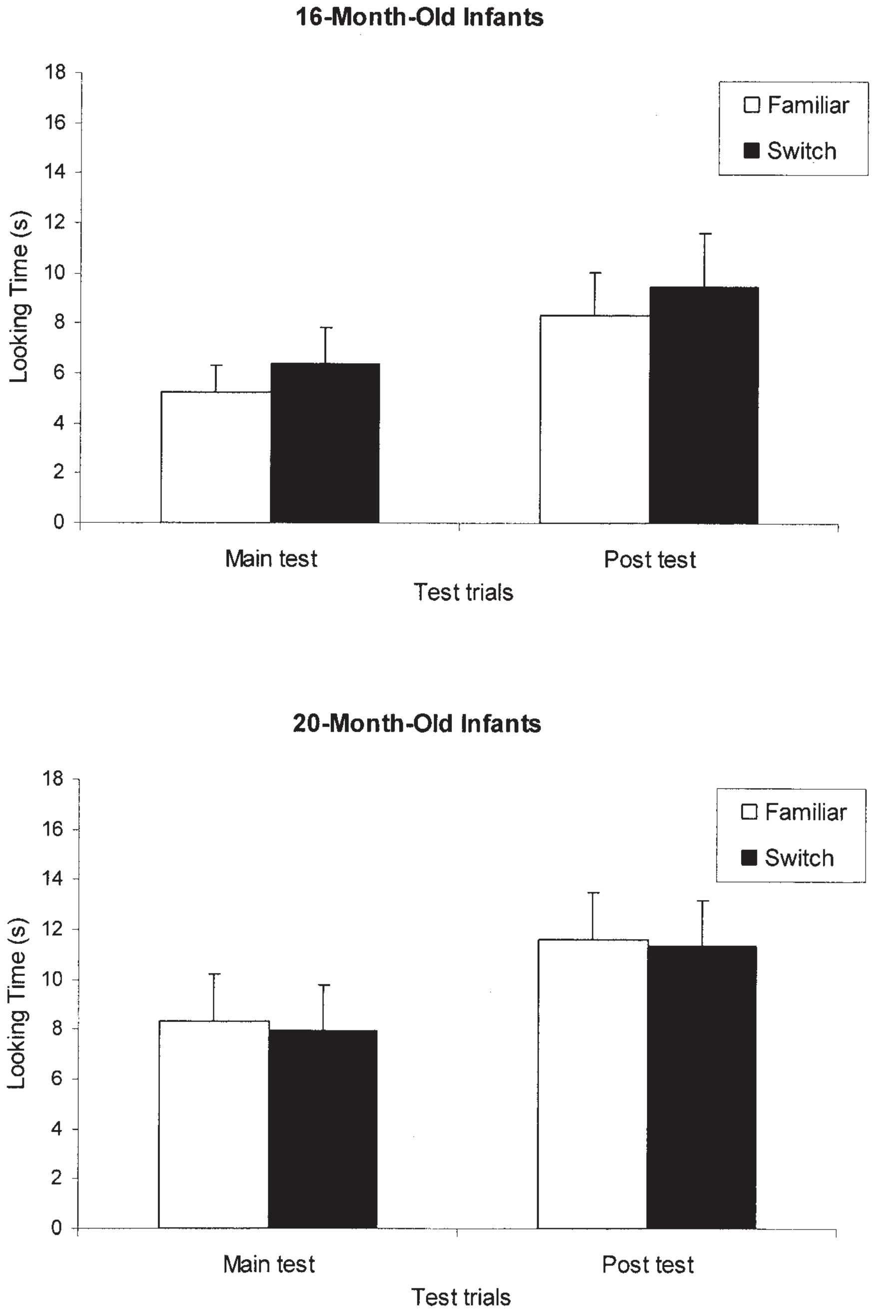

Figure 3. Mean looking times and standard errors (depicted by vertical lines) during the two causal and noncausal test trials for 16- and 20-month-old infants in Experiment 2.

(condition: self-propelled dynamic part vs. self-propelled static part) × 2 (test trial: switch vs. familiar) mixed-design ANOVA. The analysis for the 16-month-olds revealed no main effect for condition, $F(1, 30) = 0.55$, $p > .7$, which indicated that across the two experiments, infants looked equally long at the switch trial and the familiar trial. There was also no significant effect for test trial and no significant interaction between the variables. The analysis for the 20-month-olds revealed a significant effect for test trial, $F(1, 30) = 4.15$, $p < .05$, which was mediated by a significant interaction between condition and test trial, $F(1, 30) = 6.06$, $p < .025$. This reliable interaction indicated, as would be predicted from the results of the first two experiments, that 20-month-olds looked significantly longer at the switch event than at the familiar event in Experiment 1, but they looked for equally long times at the two events in Experiment 2. There were no additional significant effects in the 20-month-olds' data.

Discussion

Experiment 2 was designed to examine whether infants at 16 and 20 months of age would learn a relation involving an object feature and movement without external cause that is counter to what is more commonly encountered in the real world, that is, when an object with a static part moves without external force. The rationale for this design was to examine whether 20-month-old infants' performance in Experiment 1 was facilitated by their knowledge of these relations or was generated online. Consistent with Experiment 1, infants at 16 months of age did not learn the relation in the events; that is, they did encode that the second object possessed a static feature and that the first object possessed a dynamic feature. However, in contrast to the first experiment, infants at 20 months of age also did not learn the relations in the events between parts and onset of motion. This pattern of behavior may be explained by the fact that older infants may have sufficient experience in the real world with events involving self-propulsion to have learned that things that move without external force tend to possess dynamic features. Consequently, they will encode relations that are consistent with this prior experience and not those that are inconsistent with it.

Experiment 3

A final question to be addressed concerns the developmental trajectory for knowledge acquisition of self-propulsion. Of import is whether infants between 16 and 20 months of age are unconstrained in the relations they will encode relating to onset of motion and static and dynamic parts. Previous research has shown that before infants learn which features are typical of agents and recipients, they will associate any part—a static one or a dynamic one—with agency or recipiency (Rakison, 2005). A similar developmental trajectory was predicted here in relation to infants' attention to correlations involving object parts and onset of motion. Thus, Experiment 3 was designed to examine whether infants at 18 months of age will learn the relation between a static part and movement without external cause. This issue was addressed by presenting a single group of infants at 18 months of age with the events used in Experiment 2. This condition alone was used because there was no reason to expect, on the basis of previous research, that infants at 18 months of age would not learn relations consistent with those in the real world.

Method

Participants. Sixteen healthy full-term 18-month-olds (mean age 17 months 16 days; range = 17 months 4 days to 18 months 8 days) acted as participants in the experiment. There were an equal number of boys and girls. Data from an additional 8 infants were excluded from the final sample: 2 because of a failure to habituate, 3 because of fussing or crying, and 3 because of technical difficulties. Infants were recruited in the same way as they were in Experiments 1 and 2 and were presented with a small gift for their participation.

Stimuli, design, and procedure. The stimuli, design, and procedure were the same as those used in Experiment 2.

Results

Infants' mean visual fixation times for the two conditions are shown in Figure 4. Paired-sample *t* tests were used to compare infants' looking times to the noncausal familiar and switch test events as well as the two causal posttest events. The analysis for the noncausal events revealed that infants looked significantly longer at the switch event ($M = 8.76$ s, $SD = 6.17$ s) than the familiar event ($M = 3.98$ s, $SD = 3.21$ s), $t(15) = 2.35$, $p < .05$. This suggests that infants at 18 months of age have learned the relation between a static part and self-propulsion. The analysis for

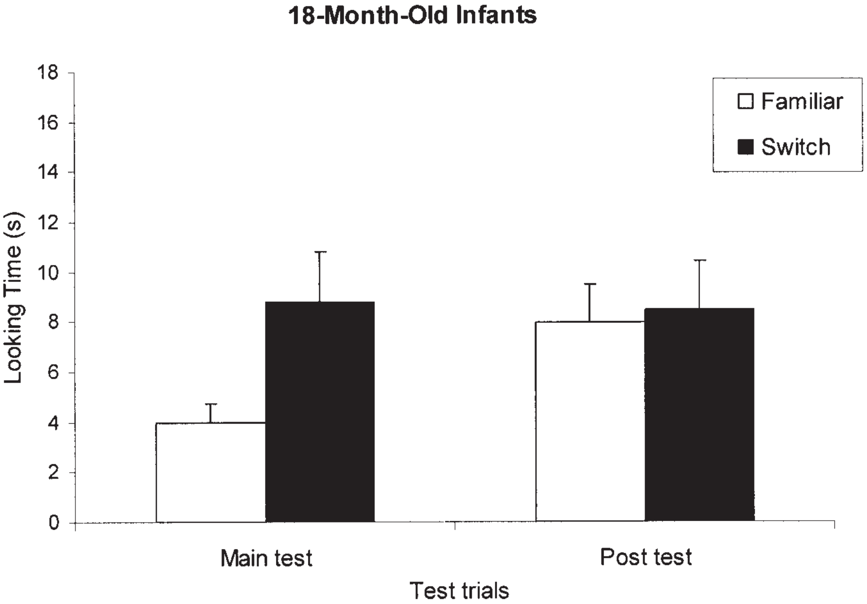

Figure 4. Mean looking times and standard errors (depicted by vertical lines) during the two causal and noncausal test trials for 18-month-old infants in Experiment 3.

the two posttest events indicated that infants looked equally long at the causal switch event ($M = 8.45$ s, $SD = 9.43$ s) and the causal familiar event ($M = 7.96$ s, $SD = 8.01$ s), $t(15) = 0.25$, $p > .7$. A final analysis compared infants' looking times to the familiar noncausal event and the first posttest causal event. Consistent with the analyses from the first two experiments, this analysis showed that infants looked longer at the first causal event ($M = 9.35$ s, $SD = 7.76$ s) than the familiar noncausal event, $t(15) = 2.34$, $p < .05$. Thus, infants at 18 months of age perceived the habituation events as noncausal and differentiated them from the causal events.

Discussion

Experiment 3 was designed to examine whether infants at 18 months of age will learn relations involving an object part and onset of motion that are not generally observed in the real world. The rationale for this design was that if infants at this age are able to encode such relations but have not yet learned that objects in the real world that move without external cause tend to possess dynamic features, they will associate a static part with self-propulsion and a dynamic part with ambiguous onset of motion. The data revealed that infants at 18 months of age learned the relations that were inconsistent with those in the real world. This finding, in conjunction with those of the first two experiments reported here, is consistent with the developmental trajectory observed in 12- to 16-month-olds' learning about the features of agents and recipients in a causal event (Rakison, 2005).

General Discussion

My goals in the experiments reported here were twofold. First, the experiments were designed to examine whether infants can associate a dynamic or static feature with movement that begins without an apparent external cause. Second, they were devised to investigate the developmental trajectory involved in infants' learning about the features that are typical of self-propelled objects. Of particular relevance was whether infants undergo a similar developmental course when they learn about objects' onset of motion as when they learn about their causal role in an event (Rakison, 2005); that is, a key question was whether infants will initially learn relations that are inconsistent with those in the real world and then later be more selective in the relations to which they will attend. These issues were addressed by showing 16-, 18-, and 20-month-olds noncausal events with novel geometric figures in which one object moved without physical contact from another object. Experiment 1 revealed that infants at 20 months of age but not those at 16 months of age associated a dynamic part with self-propulsion. Experiment 2 showed that infants at neither 16 months nor 20 months of age will learn relations between a static part and movement without an external cause. Experiment 3 indicated that infants at 18 months of age will associate a static part with self-propulsion even though this relation is generally incongruent with the regularities found in the real world.

The results of the experiments indicate that the relation between the type of part of an object and whether that object moves without an external cause is sufficient for infants to learn which things are self-propelled and which things are not. Recall that the objects in the noncausal habituation events were identical except for whether they possessed a dynamic part or a static one, and infants' looking behavior was not driven by which object moved on-screen first (as shown by the posttest trials). Consequently, the only basis on which infants could recover visual attention in the noncausal switch trials was because of the change in the parts possessed by the two objects in the events. The first object in the event exhibited an ambiguous onset of motion in that it moved from offscreen until it stopped. Moreover, whether this object possessed a dynamic or static part was immaterial to interpreting the event as involving self-propulsion. The second object, in contrast, displayed a motion characteristic that adults interpret as typical of animate entities—it moved without external cause—and whether it possessed a dynamic or static part was more central to interpreting the event. This suggests that the looking behavior of 20-month-olds in Experiment 1 was most likely determined by the relation between the second object's part and the perception that this object moved without external force. That infants rapidly learned the relation between a part type and self-propulsion when presented with two essentially identical objects suggests that such probabilistic relations are readily acquired in the real world after repeated observations of various entities that exhibit this motion characteristic.

At the same time, the data across the experiments suggest that the basis for the three age groups' behavior may have been quite different. Infants at 16 months of age did not learn any of the relations in the events and infants at 18 months learned relations that were inconsistent with those that are commonly found in the real world. This suggests that infants in these age groups may have come to the task with little knowledge about the features typical of self-propelled entities. In contrast, infants at 20 months of age learned only the relations that are more common with their experience, which suggests that their knowledge of such relations constrained the ones they would learn within a laboratory setting. This pattern of findings does not necessarily mean that it is not until after 16 months of age that infants start to learn about the identity of self-propelled objects; for instance, infants at that age or even younger may have associated a dynamic part with self-propulsion if the stimuli were more distinctive or if the parts of the stimuli were larger or more prominent. However, the data do suggest that by 20 months of age, infants have knowledge that the world is composed of things that are self-propelled and things that are not self-propelled. Note that the claim here is not that this knowledge is comparable to that of adults, who understand that self-propelled entities are alive; act as agents; and possess eyes, hearts, and desires, among other things. Rather, the experiments reported here show that by 20 months of age, infants are able to perceive that certain objects are self-propelled, and they expect those objects to possess certain kinds of features.

The developmental trajectory observed in the current experiments is consistent with the trajectories found in recent studies of a wide range of cognitive phenomena in infancy. Madole and Cohen (1995), for instance, found that 18-month-olds will learn form–function relations that are congruent with those in the real world, whereas 14-month-olds will learn form–function relations that are congruent and incongruent with those in the real world. Likewise, 24-month-old infants will learn only iconic gestures, whereas 18-month-old infants will encode arbitrary as well iconic ones (Namy et al., 2004), and 14-month-olds are unable to make the same kind of fine-grained syllable discriminations as 8-month-olds are (Stager & Werker, 1997). Finally, 16-month-olds will associate a dynamic part but not a static part with agency and a static part but not a dynamic part with recipiency, whereas 14-month-olds will associate either part type with either causal role (Rakison, 2005). I propose that the uniformity among the developmental trajectories observed in these diverse domains signifies that the same general mechanism may underlie learning in each of them. Elsewhere, I have suggested that this developmental trajectory emerges because of a process called constrained attentional associative learning (Rakison, 2005), which builds on the view that conceptual development is best depicted as a continuous enrichment of initial representations (Eimas, 1994; Jones & Smith, 1993; Quinn & Eimas, 1997; Rakison, 2003, 2005; Rakison & Poulin-Dubois, 2001).

This developmental trajectory is illustrated in Figure 5 for how infants perceive and encode relations involving self-propulsion and agency and recipiency. Thus, infants are unable initially to attend to certain relations, presumably because of limited memory and information-processing abilities (see also Oakes & Madole, 2003; Rakison & Lupyan, 2006). As these abilities improve, infants become able to encode a wider range of ever more complex relations, yet they are unconstrained in those to which they will attend. Once infants' experience with the same feature–feature relations in the world causes the represented associative link between those features to be strengthened, attention is constrained or directed to such relations and not others. However, at some point later in development, these attentional constraints must be relaxed in a number of domains so that the appropriate representations can match more precisely the relations in the world. For example, infants will initially learn that recipients of an action possess static parts because this is a common relation that they will encounter; yet later they must learn that recipients can also possess dynamic parts, such as when a person is pushed by another person (see also Namy et al., 2004).

An important question that needs to be addressed is why infants might develop knowledge about self-propelled objects later in development than they learn about agents and recipients of a causal action (Rakison, 2005). One feasible possibility is that infants are exposed to more causal events than self-propelled ones. It is common, for example, for objects and entities to move across an infant's line of sight, but in many cases the origins of that movement may not be observable. An alternative explanation is that infants may observe equally often events involving self-propulsion and causality, but the relation between parts and the specific actions within those events in less evident. When people act as a causal agent, for instance, hands grasp, arms reach, and mouths open and close. In contrast, when people move without an external cause, the parts involved in that action (i.e., legs) may be obscured from view. Regardless, the results of the current experiment in conjunction with those of Rakison (2005) are among the first to show that with the same stimuli, infants develop knowledge of the features typical of agents and recipients before they learn about the features typical of self-propelled objects. A corollary of this conclusion is that infants may learn about the various motions of objects and entities in the world in a somewhat piecemeal fashion during the first and second years of life (Rakison & Poulin-Dubois, 2001).

Finally, it is worth noting some potential criticisms of the present studies. First, as discussed earlier, it is impossible to eliminate the possibility that infants learn about aspects of self-propulsion earlier than suggested here. Although the data support the view that that it is not until 20 months of age that infants

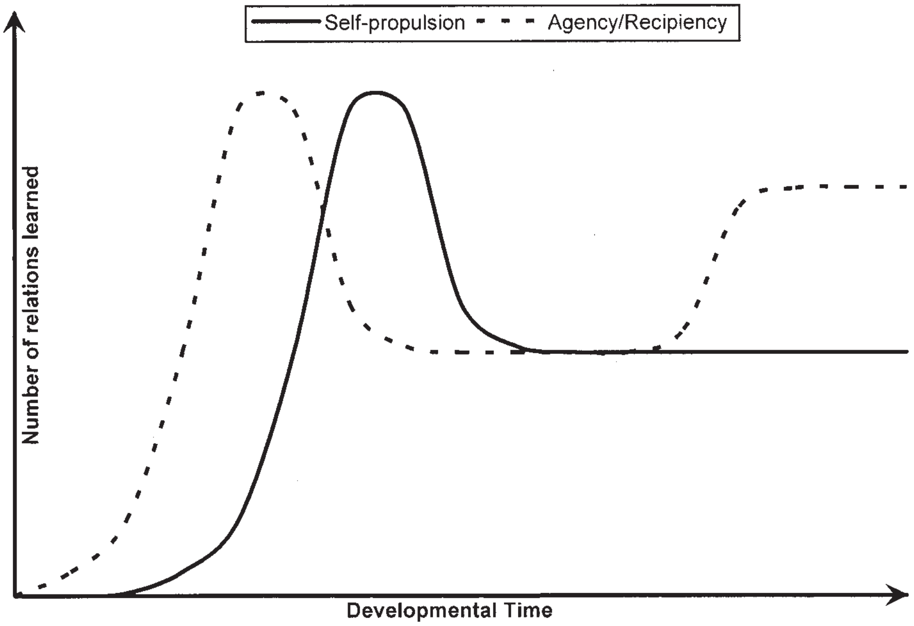

Figure 5. Developmental trajectory for early learning about self-propulsion (based on the current experiments) and agency and recipiency (based on Rakison, 2005). The figure demonstrates that infants are unable initially to encode certain relations, after which they are unconstrained in the relations to which they will attend. Prior experience then limits or guides attention to some relations and not others. Finally, for agency and recipiency, these constraints must be relaxed to incorporate more accurately the state of relations in the world.

associate self-propulsion with a dynamic part, it is plausible that figures that are more discreet may have allowed younger participants to learn appropriately the identity of the self-propelled object in the events. The rationale for using geometric figures was, as in other recent work (Rakison, 2004, 2005; Rakison & Poulin-Dubois, 2002), to examine infants' mechanism of learning for motion properties rather than their specific knowledge of particular categories or category exemplars. However, it is important also to show that infants have similarly associated dynamic parts and self-propulsion for real-world objects. Ingenious research by Arterberry and Bornstein (2002), for example, showed that infants are sensitive to point-light displays for animals and vehicles. Although one explanation for these findings is that infants categorized circular versus pendulum motion, it is possible that the use of point-light displays may be a productive avenue to explore infants' perception of self-propulsion.

Second, it is impossible to draw a strong conclusion from this set of experiments about the learning mechanism that allows infants to learn about the dynamic parts of self-propelled entities. The experiments reported here show only that associative learning is sufficient for infants to develop concepts about such movement; they do not show that such learning is indeed the way in which infants acquire concepts that encapsulate information about self-propulsion or other motion properties. A number of theorists have argued, for example, that infants possess specialized processes or modules that support rapid learning about objects' motion properties (e.g., Leslie, 1995; Mandler, 1992). Unfortunately, it remains to be seen whether this issue can be addressed empirically because it is difficult to envisage any study that could provide indisputable evidence in favor of domain-general or domain-specific learning. The current set of experiments, then, should be viewed as a demonstration that associative learning can in principle and in practice account for how infants learn about the dynamic features of things that move without an external cause.

Third, it is possible that the 18-month-old infants in the current experiments did not respond to the events on the basis of self-propulsion but instead applied their knowledge of the properties of agents and recipients. Recall that Rakison (2005) found that by 16 months of age, infants have learned that agents possess dynamic parts and recipients possess static parts. One explanation, then, of the 18-month-olds' behavior is that they overgeneralized this principle—that the first object should possess a dynamic part and the second object should possess a static part—to the noncausal habituation and test events used here. Although this account cannot definitively be ruled out, a number of factors cast doubt on its plausibility. First, it is well established that infants considerably younger than 18 months of age can discriminate between and respond differently to causal events and noncausal events (Oakes & Cohen, 1990). Second, infants as young as 7 months of age and as old as 16 months of age do generalize agency or recipiency to stimuli in noncausal events; that is, they recognize that attributes that are true for particular objects or roles in one type of event may not generalize to the corresponding objects or roles in the other types of events (Leslie & Keeble, 1987; Rakison, 2005). Third, the behavior of the 18-month-olds in the posttest events in the current experiments was not consistent with this interpretation (although looking times in these events could have been affected by the switch noncausal test trial).

Finally, it could be argued that although infants in the current experiments attended to the relation between a dynamic part and self-propulsion, in the real world, they may encode the relation between other features such as eyes and self-propulsion. In other words, infants in the real world may associate self-propulsion with object parts that define a category (e.g., eyes for mammals) and that are salient (e.g., eyes are areas of high contrast). The current data certainly do not eliminate this possibility; yet, at the same time, they suggest that dynamic parts play an important role in infants' developing object concepts that incorporate self-propulsion. For example, the pattern of findings of the 20-month-olds suggests that they have learned that self-propelled objects tend to possess dynamic parts, in that 20-month-olds are constrained in the relations they will encode involving a part and movement without an external cause. In addition, a recent analysis of the semantic feature production norms generated by McRae, Cree, Seidenberg, and McNorgan (in press) suggests that motion characteristics and the parts involved in those motion characteristics are central to adults' representations of animates (Rakison & Lupyan, 2006). Last, it is worth noting that the crux of the theoretical position I have forwarded here and elsewhere (Rakison, 2004, 2005; Rakison & Poulin-Dubois, 2001) is that infants are biased to attend to object parts precisely because they move and do so when the object to which they attached engages in some kind of global motion.

In summary, the three experiments reported here show that the relation between an object's dynamic or static part and its type of onset of motion is sufficient to account for how infants represent features typically possessed by self-propelled entities. Infants at 16 months of age failed to learn any relations between parts and self-propulsion, whereas infants at 18 months of age were unconstrained in the relations they would learn within the habituation procedure. That is, they encoded relations between moving without an external cause and a part type that is generally inconsistent with the probabilistic regularities found in the real world (i.e., when the object's part was static). Infants at 20 months of age were constrained, presumably because of their greater experience with objects that move without external cause, in the relations they were willing to learn (i.e., only when the object's part was dynamic). On the basis of these data and previous research with the same stimuli (Rakison, 2005), I proposed that infants acquire knowledge about the properties of objects and entities through a form of constrained attentional associative learning whereby developing representations of experience with statistical regularities in the real world restricts the information that will be encoded in the future. In addition, it was also suggested that the developmental trajectory revealed by these experiments, which matches that found in studies of early learning in language, animacy, and gesture, implies that the same mechanism may underpin concept development across a wide range of domains.

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Received April 29, 2005
Revision received February 6, 2006
Accepted June 27, 2006 ■