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Who Is the Dynamic Duo? How Infants Learn About the Identity of Objects in a Causal Chain

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Four experiments investigated infants' and adults' knowledge of the identity of objects in a causal sequence of events. In Experiments 1 and 2, 18- and 22-month-olds in the visual habituation procedure were shown a 3-step causal chain event in which the relation between an object's part (dynamic or static) and its causal role was either consistent or inconsistent with the real-world. In Experiment 3, 22-month-olds were tested with a delayed launching causal chain in which the second object, rather than the first, was the agent of the outcome. In Experiment 4, adults were shown the same events and were asked to judge whether the first or second object in the causal chain was animate or inanimate. Experiments 1 and 2 revealed that 18-month-olds were unconstrained in the part-causal role relations they would encode, but 22-month-olds learned only those relations that were consistent with the real-world. Experiment 3 showed that 22-month-olds expect the second object in a delayed launching sequence to possess a dynamic, moving part. Experiment 4 showed that adults expect the first object of a causal chain to be animate and the second object to be inanimate. The results are discussed with regard to the developmental timetable for causal learning and the mechanisms for early concept acquisition.

Keywords: infancy, causality, animacy, correlation, association

The ability to perceive and understand causality is fundamental to infants' emerging knowledge of the relationships between the various objects and entities in the world. According to a number of theorists, infants and preschoolers learn that an essential distinction between *animate* entities (e.g., people, animals, and insects) and *inanimate* objects (e.g., vehicles, plants, and furniture) is that the former often act as agents—they are the cause of an action—whereas the latter often act as recipients because they are acted on (e.g., Gelman, 1990; Leslie, 1995; Mandler, 1992; Rakison & Lupyan, 2008). As a result of this theoretical interest, infants' ability to perceive and understand simple causal events has been the focus of extensive empirical research (e.g., Cohen, Rundell, Spellman, & Cashon, 1999; Leslie & Keeble, 1987; Oakes & Cohen, 1990). Nonetheless, relatively little is known about how and when infants learn which kinds of objects tend to be agents or recipients in a causal event, especially in more complex but nonetheless common causal chains in which three objects are involved. The primary goals of the experiments presented here were to examine the developmental trajectory for infants' ability to learn about the identity of objects in a three-step causal chain and to provide insight into the mechanism that supports this learning.

There is a general consensus that the ability to perceive causality emerges around 6 months of age. In a series of classic studies, Leslie and Keeble (1987) habituated and tested infants with simple *direct launching* events in which one object contacts another object that then moves away, or *delayed launching* events in which one object contacts another object that then moves away after a delay. They found that 6.5- to 7-month-olds who were habituated to the direct launching event dishabituated to the reversal of the event—in which the previous recipient now acted as the agent—but infants who were habituated to the delayed launching event did not dishabituate to the reversal of the event. The authors interpreted this to mean that infants who were habituated to the direct launching event were responding to the causal change in agent-recipient relations whereas those in the delayed launching event did not (because no such relations existed). In an extension of this work, Oakes and Cohen (1990) used similar events but also habituated and tested infants with a *noncontact* event. They found that 6-month-olds cannot discriminate causal from noncausal events but that 10-month-olds discriminate causal from noncausal events and responded to different noncausal events as equivalent.

In a seminal study, Cohen et al. (1999) examined when infants understand a causal sequence of events—or causal chain—that leads to an outcome. In the direct launching condition, infants at 10 and 15 months of age were habituated to events in which one object (i.e., Elmo in a car) moved from off-screen until it contacted a second object (i.e., Dino in a car) that then moved until it hit a third object (a house). The final object did not move on contact with the second one but instead a puppy's head appeared. During the test events, infants were shown the same event as that seen during habituation except that the first or second object was novel (i.e., Rhino). Infants in the delayed launching condition were shown the same events except that the second object did not move until after a short delay. The authors reasoned that infants would look longer at the test event with the novel object depending on which of the first two objects they ascribe with agency; for example, if infants interpreted the first object as the causal agent

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they should look longer when the first object was changed rather than when the second object was changed.

The results of the Cohen et al. (1999) study showed that 10-month-olds in both the direct launching and delayed launching condition looked longer when the first object in the sequence was replaced with a novel object. This suggests that the 10-month-olds did not respond to the events in terms of the agent of the final outcome but rather focused on the first object in the sequence. In contrast, 15-month-olds in the direct launching condition looked longer when the first object was replaced with the novel vehicle than when the second vehicle was replaced, whereas those in the delayed launching condition looked longer when the second object was novel than when the first object was novel. This suggests that it is not until 15 months of age that infants attribute agency to the first object of a simple casual event as well as a more complex causal chain with two causal episodes.

Despite the large database on the emerging ability to perceive events as causal and to ascribe conceptual roles to the objects in them, there is relatively little empirical evidence about how and when infants learn that animate entities tend to be the cause of an action and that inanimate objects tend to be recipient of an action. There is evidence that infants expect human hands to move toward goals and act as an agent through contact with the goal-object (e.g., Leslie, 1984; Saxe, Tenenbaum, & Carey, 2005; Woodward, 1998). However, only a handful of studies have used a wider range of agents and recipients and these have provided conflicting and inconclusive evidence. For example, Spelke, Philips, and Woodward (1995) found that 7-month-olds expect that inanimate objects—but not people—require contact to move, whereas Leslie (1984) found that 7-month-olds treated as anomalous an event in which a human hand seemed to pick up a doll without contact but did not find anomalous the same event with a wooden block.

One series of studies by Rakison (2005) examined whether infants expect agents and recipients in causal events to possess specific object features. The rationale for the studies was that infants may be sensitive to, and consequently encode, the statistical relationship between the appearance of objects in the real world and whether they tend to be agents or recipients in a causal event. Animate entities (e.g., people, animals) in the real world are assumed to be more likely to act as agents and possess dynamic parts (e.g., legs, arms, hands, and eyes) that move during a causal event; for instance, during events in which a human acts as a causal agent, legs move, arms reach, and hands open to grasp objects. Inanimate objects, in contrast, are assumed to be recipients of an action and often have static, nonmoving parts; for example, coffee mugs, soccer balls, and pens tend to have no moving parts and are generally acted upon by animate agents. Support for these assumptions was found by Cicchino, Aslin, and Rakison (2011) who analyzed data from a head-cam worn in naturalistic settings by a single infant at 3, 8, and 12 months of age. The data revealed that the infant was over 27 times more likely to observe a person act as an agent in causal events than an inanimate object act as an agent, and the observed frequency of agentive events performed by a person increased with age. This suggests that over developmental time, infants will be increasingly exposed to animates (typically, people with dynamic parts) acting as agents, and as a result they will generate associatively based representations that incorporate the features of those animates and their role as an agent in a causal event. Before the formation of these representations, it is assumed that infants are unconstrained in the relations they will learn between object parts and the causal role of the object attached to those parts. In other words, when infants possess no representation of the objects and features that are associated with agency or recipiency, they will be just as likely to learn that the reverse is true (if exposed to those relations). However, once these representations are sufficiently strong—presumably as a result of increased exposure to part-causal relations in the real-world—infants should only learn those relations that are consistent with their prior experience.

To test this hypothesis, Rakison (2005) habituated 12-, 14-, and 16-month-old infants with simple Michotte-like causal events comparable 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 placed on their top. Across a series of experiments, infants were habituated to events in which an object with either a dynamic or a static part acted either as an agent or as a recipient. The infants were then tested with a familiar event and one in which the type of part (dynamic or static) was switched across the agent and the recipient. The results of the experiments showed that 12-month-olds failed to learn the part-causal role relations in the events. However, 14-month-olds learned that agents or recipients can possess dynamic or static parts; in other words, they were not constrained in their learning and encoded relations that were consistent and inconsistent with those in the real-world. In contrast, 16-month-olds learned only that agents have dynamic parts and that recipients have static parts but not the reverse. Based on these data, it was assumed that this constrained learning resulted from the oldest age group's greater experience with the statistical regularities of objects' appearance and their causal role in the real-world. Although it is also the case that a number of inanimates also possess moving parts—trains, cars, and clocks, for example—these objects are less likely to act as agents or intermediaries in a causal chain, and in many cases an animate entity would actually be the proximate cause of those objects' motion. Moreover, given the likely base-rates of animates acting as agents in causal events (Cicchino et al., 2011), even if infants were to observe such events they would be unlikely to override or interfere with their previously formed representations.

Despite these findings, little is known about infants' expectations about the identity of objects in a causal chain sequence. Consequently, the main aims of the present experiments were twofold. First, the studies were designed to test whether infants associate specific object features—namely, dynamic and static parts—with the agent and intermediary object in a causal chain. Second, the experiments were designed to examine whether the same developmental pattern outlined above exists for infants' learning about the features of agents and intermediaries in a causal chain. Infants at 18 and 22 months of age were habituated to a causal chain similar to that used by Cohen et al. (1999); however, the first two objects (Objects A and B) were identical to those used by Rakison (2005) and possessed either a dynamic part or a static part. The third object (Object C) was a rectangular shape from which a star emerged after it was contacted by Object B. The design of Experiments 1, 2, and 3 are presented in Table 1. In Experiment 1, infants were habituated to a causal chain consistent with that found in the real-world (the agent, or Object A, possessed a dynamic part and the intermediary object, or Object B, possessed

Table 1
Outline of Experiments 1, 2, and 3 With 18- and 22-Month-Old Infants

	Causal chain?	Object A	Object B	Consistent with real-world?
Experiment 1	Yes	Dynamicpart	Static part	Yes
Experiment 2	Yes	Static part	Dynamic part	No
Experiment 3	No	Static part	Dynamic part	Yes

a static part). In Experiment 2, infants were habituated to a causal chain that was inconsistent in the real-world (Object A possessed a static part and Object B possessed a dynamic part). In Experiment 3, infants were habituated to a three-step event in which there was a delay after Object A contacted Object B; in this event, Object B was the cause of the star emerging from Object C, and it possessed a dynamic part and Object A possessed a static part. Experiment 4 examined adults' interpretation of the events that were shown to infants in the first three experiments.

Based on previous findings (e.g., Rakison, 2005, 2006), it was predicted that younger infants would be unconstrained in their learning such that they would encode events in which Object A or Object B possessed a dynamic part regardless of whether they were consistent or inconsistent with the real-world. Although the youngest infants in the current studies were older than those in Rakison (2005, 2006), this pattern was predicted for causal-chain events because of their greater complexity; infants had to process the identity of three objects—rather than two—as well as the interaction among those three objects. It was also predicted that older infants, following greater experience with causal chains in the real-world, would encode only those causal chain events in which the first object possessed a moving part and the second object possessed a static part. This too follows from previous work that showed that prior learning about part-causal role relations constrains what information will be learned in the future.

Experiment 1

This experiment was designed to examine 18- and 22-month-old infants' ability to associate the role of agency with a dynamic part and the role of intermediary with a static part in the context of a causal chain. Infants were habituated to a causal chain event that was consistent with the real world—in which Object A possessed a dynamic part and Object B possessed a static part—and then tested to see if they learned the relations in the events. It was predicted that infants would look longer at the novel test trial than at the familiar test trial if they are able to associate specific parts with specific roles in a causal chain event.

Method

Participants. The participants were 12 18-month-olds (mean age 17 months 28 days; range = 17;16 to 18;12) and 12 22-month-olds (mean age 22 months 1 day; range = 21;15 to 22;12) healthy full-term infants. There were 7 females and 5 males in the 18-month-old group and 7 males and 5 females in the 22-month-old group. The majority of infants were White and of middle socioeconomic status. Data from 10 infants (8 18-months-olds and 2 22-month-olds) were excluded from the final sample, 3 because of fussing, 2 because of parent interference, 4 for looking more than 2 *SD* beyond the condition mean, and 1 because of technical problems. Infants were recruited through birth lists obtained from a private company and were given a small gift for their participation.

Stimuli and design. The habituation and test stimuli were computer-animated events created with Macromedia Director 8.0 for PC. In each event, a geometric figure (Object A) moved horizontally from off-screen until it contacted an identical second geometric figure (Object B) that was situated at the center of the screen. At the point of contact, a "clunk" noise was heard and Object A stopped moving and Object B began to move in the same direction as the first object. Object B continued to move until it contacted a third object (a green rectangle with an internal star; Object C) after which a "boing" noise was heard and a sun shape appeared from top of the object and bounced vertically several times before remaining motionless. The event is illustrated in Figure 1a and 1b. Each event lasted 8.0 s and could be repeated up to three times per trial. Each presentation of a causal event was separated by a blue screen that descended and ascended over a period of 2 s. The two geometric figures in the events were identical to those used by Rakison (2005, 2006) and were hexagonal red shapes with a yellow internal star shape and a green triangular part located on their top.

During the habituation trials, the triangular part on top of Object A moved horizontally back-and-forth throughout the event and the

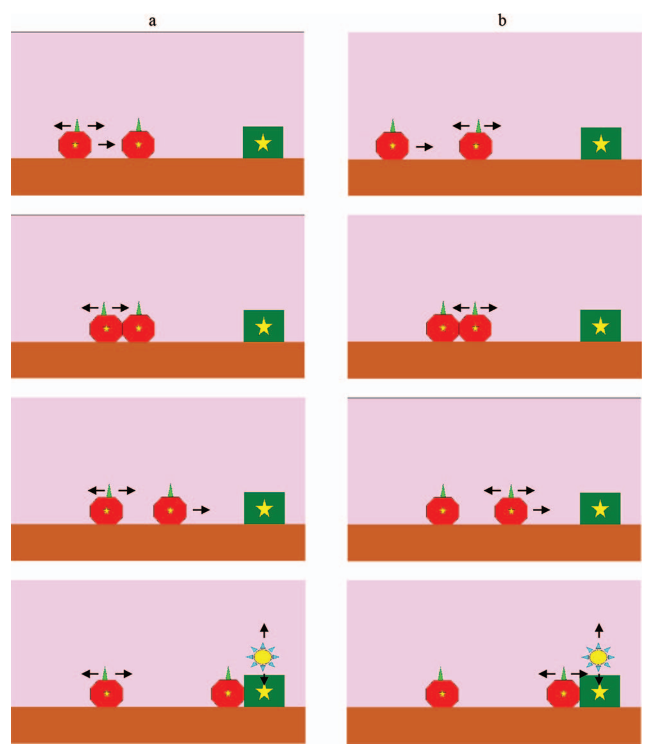

Figure 1. (a and b) Stimulus events used with infants in Experiments 1 and 2. Infants in Experiment 1 were habituated to the event portrayed in Figure 1a and then tested with that event (the familiar test trial) and the event portrayed in Figure 1b (switch test event). Infants in Experiment 2 were habituated to the event portrayed in Figure 1b and then tested with that event (the familiar test trial) and the event portrayed in Figure 1a (switch test event). See the online article for the color version of this figure.

triangular part of Object B was always static (Figure 1a). After habituation, infants were presented with two test events. The *familiar test* event was identical to that seen during habituation. The other event, the *switch test* trial, was identical to the familiar test event except that the identity of Object A and Object B was switched; that is, the triangular part of the first object was always static and the triangular part of the second object constantly moved horizontally back and forth (Figure 1b). The order of the familiar and the switch test trials was counterbalanced across infants in each age group.

Apparatus and procedure. Each infant sat on their caretaker's lap in front of a computer screen (size: 14 × 24 in.; distance: 24 in.) in a small, quiet, softly lit laboratory room. During the habituation phase, each event was presented until the infant looked away from the monitor for over 1 s or after 30 s of continuous looking. The habituation phase ended when an infant's looking time for a block of three trials decreased to 50% of that registered during the first three trials or until 16 trials were presented. The test trials were presented until the infant looked away for over 1 s or after 30 s of uninterrupted looking. A green expanding and contracting circle on a black background with a synchronous bell sound was presented before the first habituation trial and between each habituation and test trial. The experiment was controlled by Habit 2000 (Cohen, Atkinson, & Chaput, 2000) on an Apple G4 computer.

Coding and analyses. The length of the infant's visual fixations were coded by an experimenter's key press and recorded by the computer. A second judge independently recoded 25% of the each age group's looking behavior in the experiment. Reliability for infants' visual fixations in all the experiments presented here was $r > .96$, and the mean difference between the two judges on each trial was less than .32 s.

Results

The mean looking times of the two age groups during the two test trials are presented in Figure 2. Infants' looking times to the two test events were analyzed with a 2 (test trial: switch vs. familiar) × 2 (age: 18 months vs. 22 months) mixed design analysis of variance (ANOVA). The analysis revealed that across the two age groups, infants looked significantly longer at the switch test trial than at the familiar test trial, $F(1, 22) = 16.16$, $p < .001$, $\eta_p^2 = 0.42$. There was no significant effect for age of the infant, $F(1, 22) = 1.09$, $p > .3$, $\eta_p^2 = 0.05$, and no significant interaction between age and test trial, $F(1, 22) = 0.77$, $p > .3$, $\eta_p^2 = 0.04$. Planned comparisons were performed to determine whether each individual age group looked longer at the switch test trial than the familiar test trial. The analyses showed this to be the case for the 18-month-olds, $F(1, 11) = 4.86$, $p < .05$, $\eta_p^2 = 0.30$, as well as the 22-month-olds, $F(1, 11) = 12.28$, $p < .05$, $\eta_p^2 = 0.52$.

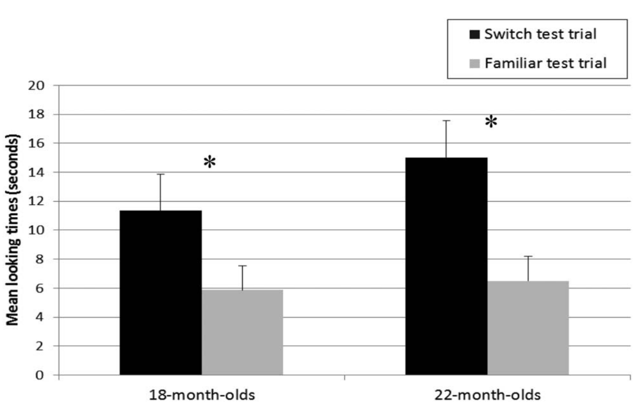

Figure 2. Mean looking time and *SE*s for 18- and 22-month-old infants in Experiment 1. * $p < .05$.

Discussion

This experiment was designed to examine whether infants are able to associate the causal role of an object in a causal chain with a single part that was either dynamic or static. The results show that infants at 18 and 22 months of age are able to learn relations between such parts and whether an object is the agent or intermediary of a causal chain. This is particularly impressive because the first and second object in the events were indistinguishable except for whether they possessed a dynamic or a static part.

There are, however, two unresolved issues from Experiment 1. A first issue is that it remains to be seen whether infants brought any prior knowledge to bear on the task or whether they learned online either that agents in a causal chain possess a dynamic part, intermediaries possess a static part, or both of these relations. Infants in both age groups, based on their experience in the real-world, may have come to the task with knowledge about the relationship between the appearance of an object—whether it has a moving or static part—and its role in a causal chain; the habituation events were consistent with those found in the real-world and may have tapped this prior knowledge. Alternatively, infants at 18 and 22 months may have no knowledge about the surface features of objects in a causal chain and may instead have learned during the task that a specific kind of part is related to a specific causal role. A second issue is that infants in this experiment may have focused only on the first two objects and did not process the event as a causal chain. The pattern of behavior of both age groups is consistent with that found by Rakison (2005) with 16-month-olds, and it is possible that infants responded to the first causal interaction alone. Experiment 2 was designed to address these issues.

Experiment 2

In this experiment, infants at 18 and 22 months of age were tested with an identical design to Experiment 1 with one exception; in the habituation event, Object A (the agent) possessed a static part and Object B (the intermediary object) possessed a dynamic part. In the test phase, infants were shown one event that switched these part-causal role relations and one event with the same relations as those seen during habituation. The motivation for this design was twofold. First, if the events tapped infants' preexisting knowledge about the features of agents and intermediaries in a causal chain they would be expected not to learn the relations in the event because they conflicted with their experience in the real-world (Rakison, 2005, 2006). In contrast, if infants had little or no such preexisting knowledge, they would be expected to learn the relations in the event. Thus, we predicted that 18-month-olds would learn the relations in the events but 22-month-olds—because of their greater experience with causal chains in the world—would not.

Method

Participants. Sixteen healthy full-term 18-month-olds (mean age 18 months 4 day, range = 17;15 to 18;14), and 16 22-month-olds (mean age 22 months 3 day; range = 21;15 to 22;14) participated in this experiment. There were 8 males and 8 females in both age groups. Data provided by 14 additional infants (8 18-month-olds and 6 22-month-olds) were excluded from the final sample: 5 because of a failure to habituate, 5 because of fussing or crying, 3 for looking more than 2 *SD* beyond the condition mean, and 1 because of technical problems. 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 in Experiment 1 except that in the habituation event Object A possessed a static part and Object B possessed a dynamic part (Figure 1b). In the test phase, infants were presented with a *switch test* trial in which Object A possessed a dynamic part and Object B possessed a static part (Figure 1a) and a *familiar test* trial that was the same as the habituation event. All other aspects of the experiment were identical to Experiment 1.

Results

Infants' mean visual fixation times during the two test trials are presented in Figure 3. The looking times to the two test events were analyzed with a 2 (test trial: switch vs. familiar) × 2 (age: 18 months vs. 22 months) mixed design ANOVA. The analysis produced a marginally significant main effect for test trial, $F(1, 30) = 3.37$, $p = .076$, $\eta_p^2 = 0.10$, and a significant age × test trial interaction, $F(1, 30) = 4.76$, $p < .05$, $\eta_p^2 = 0.14$. There was no significant main effect for age, $F(1, 30) = 0.97$, $p > .3$, $\eta_p^2 = 0.03$. To examine further the interaction between age and test trial, planned comparisons were performed to examine looking times for the individual age groups. The analyses revealed that the 18-month-olds looked significantly longer at the switch test trial ($M = 12.69$, $SD = 8.73$) than the familiar test trial ($M = 5.51$, $SD = 3.51$), $F(1, 15) = 10.14$, $p < .001$, $\eta_p^2 = 0.40$. In contrast, the 22-month-olds looking times to the switch ($M = 11.12$, $SD = 11.24$) and familiar test trials ($M = 11.74$, $SD = 8.18$) were not significantly different, $F(1, 15) = 0.50$, $p > .8$, $\eta_p^2 = 0.003$.

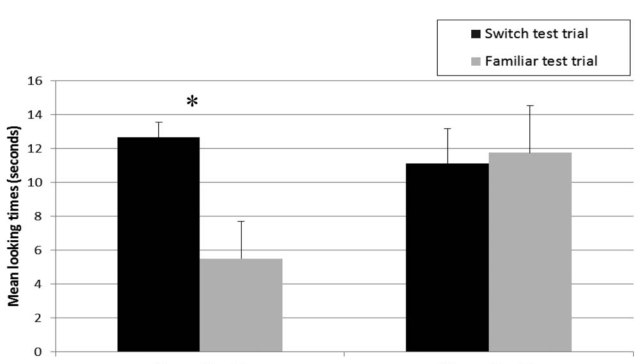

Figure 3. Mean looking time and *SE*s for 18- and 22-month-old infants in Experiment 2. * $p < .05$.

Discussion

These results demonstrate the developmental trajectory for when infants learn about the identity of objects in a causal chain. Infants at 18 months of age will learn relations that are inconsistent with the real-world, which suggests that they have not yet learned which parts are associated with the role of agent or intermediary in a causal chain; that is, they are willing to accept that the first or second object in a causal chain possesses a static or dynamic part. At the same time, 22-month-olds will not encode relations that are inconsistent with the real-world, which implies that they have learned which parts are possessed by agents, intermediaries, or both, in a causal chain. This general pattern is consistent with that found in previous studies on infants' ability to learn about the identity of causal agents and self-propelled objects (Rakison, 2005, 2006), but it also suggests that learning about objects in a causal chain may occur later—presumably because of its greater complexity—than learning about objects in a simple causal event with only two objects.

Experiment 3

The results of Experiments 1 and 2 demonstrate that 22-month-olds expect that the first object in a causal chain should have a moving part and that 18-month-olds do not have this expectation. A key question that remains is whether 22-month-old infants in the first two experiments processed the identity of the intermediary object (Object B). It is possible, for example, that infants' looking patterns in the previous experiments was determined entirely by the presence or absence of a moving part on the first object in the causal chain. To examine this issue in the current experiment, 22-month-old infants were habituated to similar events to those in the first two experiments except that after Object A contacted Object B there was a delay of 2 s (see Cohen et al., 1999, Experiment 1). In these events, Object B should be interpreted as the agent of the outcome because it was not caused to move by Object A; therefore, in the habituation events Object A possessed a static part and Object B possessed a moving part (as in Experiment 2). It was predicted that if infants encoded the identity of Object B in the event then they would look longer at a switch test event in which Object A possessed a moving part and Object B possessed a static part relative to a familiar event. Such a finding, in conjunction with those of the first two experiments, would imply that 22-month-olds are sensitive to which object in a causal chain of three objects is the agent of the final outcome.

Method

Participants. Sixteen healthy full-term 22-month-olds (mean age 21 months 28 days, range = 21;14 to 22;17) participated in this experiment. There were 10 males and 6 females. Data provided by 10 additional infants were excluded from the final sample, 6 because of fussing or crying, and 4 for looking more than 2 *SD* beyond the condition mean. Infants were recruited in the same way as the first two experiments and were given a small gift for their participation.

Stimuli, design, apparatus, and procedure. The stimuli were the same as those in Experiments 1 and 2 except that there was a 2 s delay after Object A contacted the Object B. After this delay, the second object moved to contact the third object (Object C). During the habituation event, Object A possessed a static part and Object B (the agent) possessed a dynamic part (Figure 1b). In the test phase, infants were presented with a switch delayed launching test trial in which Object A possessed a dynamic part and Object B (the agent) possessed a static part (Figure 1a) and a familiar delayed launching test trial that was the same as the habituation event. All other aspects of the experiment were identical to Experiment 1 and 2.

Results and Discussion

A single-factor ANOVA revealed that infants looked significantly longer at the switch delayed launching test trial ($M = 11.16$, $SD = 8.59$) than at the familiar delayed launching test trial ($M = 5.50$, $SD = 4.65$), $F(1, 15) = 5.36$, $p < .05$, $\eta_p^2 = 0.26$. This finding, in conjunction with the previous experiments, suggests that by 22 months of age infants are able to determine which object in a three-step causal chain is the agent of the final outcome, and they expect the primary cause—the first object in a direct launching sequence and the second object in a delayed launching sequence—to possess a dynamic, moving part. To this end, across-experiment analyses revealed that 22-month-olds' pattern of looking to the familiar and switch test trials was reliably different in the two causal chain experiments that presented relations that were consistent and inconsistent with the real-world (Experiments 1 and 2), $F(1, 26) = 5.65$, $p < .05$, $\eta_p^2 = 0.18$. However, the pattern of looking for the 22-month-olds was not reliably different for the two experiments (Experiment 1 and 3) that presented relations consistent with those in the real-world, $F(1, 26) = 0.65$, $p > .4$, $\eta_p^2 = 0.02$. Finally, the data from the present experiment also suggest that 22-month-old infants in Experiments 1 and 2 did not attend solely to whether the first or second object possessed a moving or a static part (as they did for simple causal launching events in Rakison, 2005, 2006). If this were the case, infants in the current experiment would have been expected to behave similarly to those in Experiment 2 because the same objects possessed dynamic or static parts in each one; that is, Object A possessed a static part and Object B possessed a moving part.

Experiment 4

Cohen et al. (1999) asked adults to rate the causal importance of objects in a causal chain and established that they attribute the agent role to the first object and not the second object. In a similar vein, the current experiment was designed to corroborate the assumptions that the first object in a causal chain tends to be animate and therefore have a dynamic part, and that the second object in a causal chain tends to be inanimate and have a static part. Although the first three experiments reported here demonstrate that infants have specific expectations about the parts of agents and intermediaries in a causal chain, it is important to demonstrate that adults have the same expectations. This would support the notion that infants' behavior was not the result of low-level perceptual preferences or biases for the first or second objects in the causal chain events. Adults were shown the habituation events from Experiments 1 and 2 as well as a similar event in which none of the objects possessed a dynamic part, and they were asked whether the first and second object in the causal chain was animate (e.g., a person or animal) or inanimate (e.g., a vehicle or piece of furniture). It was predicted that adults would judge the first object as more likely to be animate and the second object as more likely to be inanimate when there were no moving parts or when the moving part was attached to Object A and the static part was attached to Object B.

Method

Participants. Fifty undergraduate students (age $M = 19$ years 9 months; age $SD = 14$ months) participated in this experiment for credit in an introductory level psychology course. There were 16 females and 34 males in the final sample.

Stimuli, design, and apparatus. Participants were shown causal chain events on a 15 in. laptop computer screen in a quiet room. The stimuli in the causal chain events were identical to those shown to infants except that sound was omitted for technical simplicity.

Procedure. Participants were tested individually and were seated in close viewing range of the monitor. The experimenter gave the participant a written questionnaire to complete while watching the events. For each event, the questionnaire asked participants which kind of object from the real-world is more likely to be the first and second object in the movie. Participants were required to choose whether the first and second object was more likely to be animate (given the examples of people, animals, and insects) or inanimate (given the examples of vehicles, furniture, and plants).

Results and Discussion

Adults' responses—converted to a percentage of "animate" and "inanimate" choices for each event—are illustrated in Figure 4. Chi-square tests were performed to determine whether participants' responses differed significantly from chance. The analyses revealed significant effects for the event with objects without dynamic parts, $\chi^2(1, N = 50) = 40.40$, $p < .001$, and the event in which the first object possessed a dynamic part and the second object possessed a static part, $\chi^2(1, N = 50) = 50.32$, $p < .001$. As can be seen in Figure 4, adults were more likely to judge the first object in these events as an animate entity and the second object in these events as an inanimate object. The analyses also revealed that adults' responses were not significantly different from chance for the event in which the first object possessed a static part and the second object possessed a dynamic part, $\chi^2(1, N = 50) = 2.32$, $p > .1$.

These results show that adults have the same expectations as 22-month-old infants about the parts of objects that played different roles in the causal chain events used here. For causal chain events that were consistent with the real-world, adults indicated that animates act as agents and inanimates act as intermediaries. For causal chain events that were inconsistent with the real-world—when the agent possessed a static part and the intermediary possessed a dynamic part—they showed no such attribution. This suggests that adults, like 22-month-olds, viewed these events as conflicting with their existing knowledge. More important, although adults were influenced in their judgment by the parts of the objects in the causal chain, in the event without any such information—when both objects had static parts—they still assigned the first object as animate and the second as inanimate.

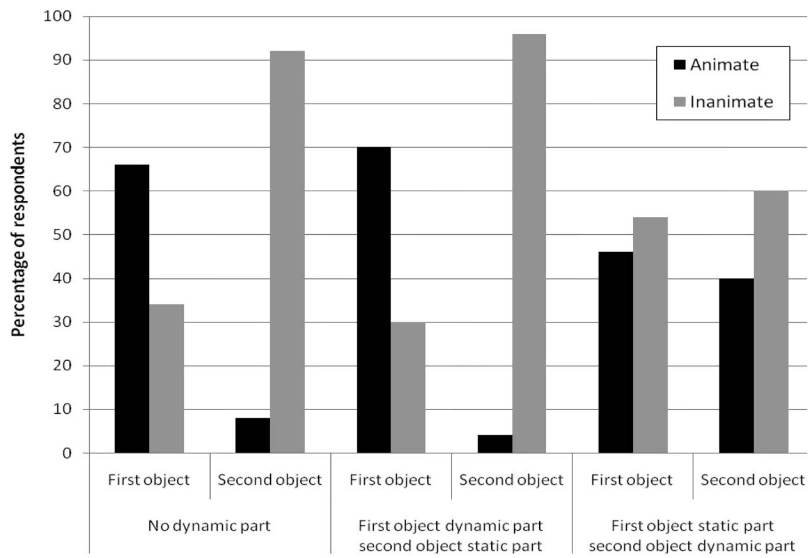

Figure 4. Percentage of choices (as either animate or inanimate) in Experiment 4 by adult participants for the two moving objects in the causal chain event.

General Discussion

The experiments reported here were designed to examine whether infants associate specific object parts with specific roles that objects play in a three-step causal chain. Experiments 1 and 2 demonstrated that infants at 18 months of age have no expectations about the parts of agents and intermediary objects in causal sequences; that is, they can learn online that either object has a static or dynamic part. The experiments also showed that by 22 months of age infants have expectations about the parts of objects in a causal sequence; they were constrained in the part-causal role relations that they would learn and did not encode those that were inconsistent with the real-world. Experiment 3 confirmed that 22-month-olds encode all three objects in a three-step causal chain: infants at this age learned that the second object in a delayed launching chain—which was the cause of the final outcome—should have a dynamic part. In conjunction, the results of the first three experiments revealed that infants were responding to the events as a three-step causal chain and not as a simpler causal interaction between the first and second object alone. Finally, Experiment 4 indicated that adults expect the agent of a three-step causal chain to be animate—and possess a dynamic part—and the intermediary of a three-step causal chain to be inanimate and possess a static part.

These data are the first to document how infants may learn about the surface appearance of objects in a three-step causal sequence. Previous research has shown that it is not until between 14 and 16 month of age that infants expect agents to possess dynamic parts and recipients to possess static parts in a simple two-step causal event (Rakison, 2005). The results of the current experiments reveal that infants' knowledge about the appearance of objects in three-step causal events does not emerge until considerably later, between 18 and 22 months of age. There are at least three reasons for the developmental lag of infants' knowledge for simple versus three-step causal events. First, causal chains are more complex events than simple launching events—they involve the interaction among three objects rather than two and involve two launching events rather than one—and as such place greater information-processing demands on the infant. Second, infants may not experience causal chains in the real-world as often as simple launching events because they occur less frequently or because only part of the causal chain is observed. Third, because Object B, and not Object A, makes contact with Object C, infants must learn to overlook or ignore this aspect of the input and focus instead on the ultimate cause (Object A). This may be particularly difficult for infants because they have a tendency—at least in the first year of life—to focus on the agent and not the recipient of an action (Oakes & Cohen, 1990). In all likelihood, all three of these factors contribute to the developmental differences between 18-month-old infants in the current studies and those in Rakison (2005).

The current data, in conjunction with previous research, also help to provide a developmental timetable for when infants learn about various aspects of causal events. Infants first perceive simple launching events as causal by around 5 to 7 months of age (Oakes & Cohen, 1990; Rakison & Krogh, 2012), and by 10 months of age they focus on the agent rather than the recipient of such events (Cohen & Oakes, 1993). Between 10 and 15 months infants assign the role of agent to the first object in a causal chain and between 16 and 18 months of age they learn that agents in simple launching event possess a dynamic part and recipients possess a static part. Finally, between 18 and 22 months they start to learn which features are typical of agents and intermediaries in causal chain events. That this developmental trajectory is underpinned by domain-general mechanisms and infants' information-processing abilities is suggested by the fact that the timetable for learning about the identity of object in simple causal events is mirrored by that found for learning about the identity of objects in causal-chain events. Indeed, we suggest that the age related changes observed here and in previous work (e.g., Rakison, 2005, 2006) result from infants' ever improving information-processing abilities, their experience with causal events in the real-world, and the constraints on learning that emerge as a result of this experience. These developmental changes make it easier for infants to process more complex events, allow them to differentiate the role of primary from secondary causes (e.g., Object A from Object B), and guide their attention toward the significant aspects of causal launching and causal chain events (e.g., the features of specific objects, which object is the ultimate cause).

It is unclear, from these data alone, when infants in the real-world learn about the features of agents and intermediaries in a three-step causal sequence. The current data suggest that between 18 and 22 months infants learn that agents in a causal chain possess dynamic parts and that intermediaries possess static parts. However, it is possible that the current experiments were not sufficiently sensitive to tap infants' knowledge of the identity of agents and intermediaries in real-world causal chains. For example, geometric figures were used here, as in previous studies (Rakison, 2005, 2006), because a goal of the experiments was to investigate the nature of infants' learning mechanism and the features associated with agency and recipiency in a causal chain and not which specific objects they associated with these causal roles. Moreover, the two moving stimuli in the events were identical and lacked many of the features typical of animates and inanimates (e.g., eyes, legs). Thus, although the current studies show that infants, by 22 months of age, have associated specific parts with specific roles that objects play in a three-step causal sequence, this knowledge may be in place earlier in life and may also be connected to other features that are typical of animates and inanimates.

The current experiments also provide important insight into the mechanism for learning about the properties of animates and inanimates in infancy. A number of studies across a broad variety of domains have established that younger infants, who have less experience with the statistical regularities in the world, are unconstrained in their learning whereas older infants will only encode stimuli that "make sense" in the real-world (e.g., Madole & Cohen, 1995; Namy, Campbell, & Tomasello, 2004; Rakison, 2005, 2006; Stager & Werker, 1997). Similarly, 18-month-olds in the present experiments learned that agents and intermediaries in a causal chain can have dynamic or static parts; in contrast, 22-month-olds learned only that agents have dynamic parts and that intermediaries have static parts. Elsewhere, it has been proposed that this same developmental trajectory is found across such a wide range of domains (e.g., language, gesture, and animacy) because the same general mechanism—namely, associative learning—underpins knowledge acquisition within each of them (Rakison & Yermolayeva, 2011). The results reported here provide further support for this view, and as such they lend weight to the idea that representational development is best described as a process of gradual enrichment or augmentation (Jones & Smith, 1993; Quinn & Eimas, 1997; Rakison & Lupyan, 2008).

According to this view, infants' general learning mechanisms—rather than innate specialized mechanisms or modules (Leslie, 1995; Mandler, 1992)—support early acquisition of knowledge about the various properties of objects and entities in the world. The current experiments add to the growing database of evidence that strengthens this position because they show that the relation between a motion property and a single dynamic or static part is sufficient for infants to learn the identity of agents and intermediaries in a causal chain event. In other words, because the objects in the events were identical other than whether they possessed a static or dynamic part, the only reason why infants would look longer at the switch events than the familiar events during the test trials is because they had learned the relation between a specific part and the object's causal role. This suggests that infants' earliest representations for agency and recipiency incorporate the relations between specific parts and specific causal roles but do not necessarily specify category membership (e.g., animals are agents) or unrelated parts (e.g., things with eyes are agents). Thus, as infants observe causal events in the world they associate the parts of the objects involved—for example, those that move when an object acts as an agent—and this association forms the foundation for their representation: objects with dynamic parts are associated with agency and those with static parts are associated with recipiency. Over developmental time, these associations are extended to include other, less relevant features (e.g., eyes) that tend to co-occur with the primary feature (e.g., legs), a view consistent with findings that the presence of certain features is not necessary for infants to interpret behaviors appropriately (e.g., Johnson, Ok, & Luo, 2007; Johnson, Slaughter, & Carey, 1998). Domain-specific approaches of infants' learning about animacy (e.g., Gelman, 1990; Leslie, 1995; Mandler, 1992) would not predict the pattern of data found in Experiments 1, 2, and 3. At the core of these approaches is the idea that by 10 to 14 months of age infants develop rich, abstract representations for animates and inanimates that are triggered by observing the movement of various kinds of objects and not by the specific features or parts of those objects. Thus, the current data do not fit well with these domain-specificity perspectives on early learning for animacy.

The results of Experiment 4 show which kinds of objects adults expect to act as agents and intermediaries in three-step causal events. These data reveal two important findings. First, adult participants expect agents in a causal chain to be animate and intermediaries in a causal chain to be inanimates. Second, adults expect agents in a causal chain to have dynamic parts and intermediaries to have static parts. In previous work (e.g., Rakison, 2005), it has been assumed that agents in simple causal events in the real-world tend to be animates and have dynamic parts and that recipients in such events tend to be inanimates and have static parts. The findings of Experiment 4 are the first to demonstrate the validity of this assumption. They are also significant because—in conjunction with Experiments 1, 2, and 3—they suggest that by 22 months of age infants' knowledge of the identity of objects in a causal chain is similar, though presumably less detailed, to that of adults.

One potential critique of the current experiments is that infants processed the habituation and test events solely based on the interaction of the first two objects; in other words, it could be argued that infants processed the first part of the events—Object A contacting Object B—and not the last part of them and therefore failed to observe the three-step causal chain. However, there are a number of reasons why, in our view, the current studies address infants' knowledge and ability to learn about the identity of objects in a causal chain rather than just a simple launching event. First, infants at 18 months of age in Rakison (2005) refused to learn that agents have static parts and recipients have dynamic parts, whereas 18-month-olds in the current experiments learned that that the first object in the chain has a static part and the intermediary object has a dynamic part (and it was not until 22 months that infants showed the same pattern as the 18-month-olds in Rakison (2005)). Second, if infants processed the events in terms of simple one-step causal events—of which there were two (A caused B, B caused C)—then in Experiment 2 the 22-month-olds should have learned the relations in the event when object B possessed a dynamic part because this object acted as an agent (by causing C to change state through contact). Finally, the data from Experiment 3 suggest that the 22-month-olds encode all three objects because they learned that in a delayed launching chain event the second object—which caused the final outcome—has a dynamic part.

A second critique of the current findings is that they are at odds with those of Cohen et al. (1999) because they found that 15-month-old infants identified Object A as the agent of a causal chain event even though the object did not possess moving parts. However, Cohen et al. (1999) replaced the agent or intermediary with a novel object whereas in the current studies we switched the identity of Objects A and B. Thus, the results of Cohen et al. (1999) demonstrate only to which object infants attended when they processed a causal chain whereas the current data demonstrate what information infants learn—or have previously learned—about the identity of Object A and B in a causal chain.

In summary, the current experiments show that the relation between an object's parts and its causal role is sufficient for infants to learn whether it is an agent or intermediary in a three-step causal chain. Moreover, the experiments reveal that infants' learning about causal chains follows the same trajectory found across a range of developmental phenomena. Younger infants are unconstrained by their limited experience and will encode relations that do not make sense in the real-world. Older infants, in contrast, are constrained by their prior representations and will learn only those relations that are consistent with the real-world. In this way, infants' exposure to the statistical regularities of the real-world—for animacy and presumably other domains—restricts the information that will be encoded in the future. These studies further strengthen the domain-general view of early concept development and show that associative learning is a powerful mechanism that allows infants to learn about the properties of the world around them.

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