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Knowing Who Dunnit: Infants Identify the Causal Agent in an Unseen Causal Interaction

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Preverbal infants can represent the causal structure of events, including distinguishing the agentive and receptive roles and categorizing entities according to stable causal dispositions. This study investigated how infants combine these 2 kinds of causal inference. In Experiments 1 and 2, 9.5-month-olds used the position of a human hand or a novel puppet (causal agents), but not a toy train (an inert object), to predict the subsequent motion of a beanbag. Conversely, in Experiment 3, 10- and 7-month-olds used the motion of the beanbag to infer the position of a hand but not of a toy block. These data suggest that preverbal infants expect a causal agent as the source of motion of an inert object.

Keywords: causal inference, infancy, Michotte, launching

A brief piece in the Metro section of a newspaper once described a man coming home to find a dead bird on the windowsill of his Manhattan apartment. Exasperated, he exclaimed, "Somebody threw a bird at my window!" As observers, we often find ourselves in a similar position, inferring the structure of an unseen causal interaction and even the existence of an invisible causal agent from just the interaction's observable effects. Nevertheless, a rich developmental (and psychophysical) literature has focused almost exclusively on perception of causality in simple interactions between two visible entities, neglecting the sophisticated causal inferences that become necessary under impoverished circumstances. The current experiments help to fill this gap in the previous literature by showing that 10- and even 7-month-old infants, like the man in the magazine, infer the existence of a unseen casual interaction and even an unseen causal agent from just the motion of an inanimate object.

A simple causal interaction, like a Michotte launching event (Michotte, 1946/1963), involves a change produced in one entity by the action of another. Within this interaction, the two entities, thus, play distinct roles: We will call these roles *receptive* and *agentive*, respectively. The roles persist only as long as the single interaction does. Imagine this archetypal causal sequence: a hand moves a billiard cue, which hits the white ball, which rolls across the table to hit the red ball, which rolls into the pocket. The billiard cue and the white ball each plays the receptive role in one causal interaction and then in the agentive role in the subsequent interaction. Infants identify and distinguish the entities playing the agentive and receptive roles in a Michotte launching event by the time they are 6 months old (Cohen, Amsel, Redford, & Casasola, 1998; Leslie & Keeble, 1987). In addition to playing temporary causal roles, though, entities possess enduring causal properties or dispositions. It is to these enduring causal properties that we refer when we categorize an entity as an inert object or as an agent. Previous work suggests that infants recognize and distinguish self-moving and intentional agents from inert objects by at least 6 or 7 months of age (Leslie & Keeble, 1987; Kotovsky & Baillargeon, 2000; Pauen & Trauble, 2006; Woodward, 1998; Woodward, Sommerville, & Guajardo, 2001). Enduring causal properties do not guarantee the causal role that an entity will play within a specific interaction. Human beings (paradigmatic agents) can be carried, pushed, pulled, tripped, or tossed into the air—all receptive roles. In the billiards example above, the cue and the white ball were both inanimate objects, playing an agentive role temporarily. Thus, in principle, the assignment to an entity of an enduring causal disposition and a causal role in one interaction are separate inferences.

Nevertheless, the dispositions of the entities in an interaction do influence our causal interpretations of specific events. For example, infants expect an inert inanimate object in the receptive role to go into motion when and only when contacted by another moving entity (Ball, 1973; Cohen et al., 1998; Kosugi, Ishida, & Fujita, 2003; Kotovsky & Baillargeon, 2000; Oakes & Cohen, 1990, 1994; Spelke, Phillips, & Woodward, 1995; Wang, Kaufman, & Baillargeon, 2003), but these expectations are suspended for a person (or other agent capable of self-generated motion) in the receptive role (Kosugi & Fujita, 2002; Schlottman & Surian, 1999;

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Spelke et al., 1995; Woodward, Phillips, & Spelke, 1993). These differential expectations also influence the infants' attempted interventions. Ten-month-old infants successfully learn that pushing a lever makes a picture move. However, even given similar temporal and spatial contingency information, the infants resist learning that pushing a lever makes a live person move (Carlson-Luden, 1979). Even 4-month-olds behave differently in response to the disappearance of an object (by reaching and touching the door) than of a person (by vocalizing; Legerstee, 1994). All of these studies, taken together, show that infants' interpretations of particular causal events are influenced by their representations of enduring causal properties of the entity in the receptive role.

It seems equally likely that infants' representations of the causal disposition of the entity in the agentive role would influence their interpretation of the interaction, although this hypothesis has not been extensively explored. As in the billiards example, an inanimate object may well play the agentive role in a single causal interaction. Note, though, that those causal interactions were part of a sequence in which the ultimate source of motion (the entity playing the original agentive role) was the human hand moving the cue. Adults generally expect an agent as the source of motion of inanimate objects and will infer the presence of a hidden agent, if none is visible. Imagine, for example, seeing a tennis ball or a shoe come flying over the backyard fence.

A classic study by Leslie (1984) first suggested that infants, too, consider a dispositional causal agent—in this case, a human hand—to be the likely cause of an inanimate object's motion. Infants watched a film of a hand either (a) move in from offscreen and stop near a stationary doll (*reach*) or (b) start near the stationary doll and then move offscreen together with the doll (*pick up*). In addition, each film involved either (a) contact, in which the hand contacted the doll or (b) no contact between the hand and the doll. Leslie (1984) observed that 7-month-old infants who were habituated to a pick-up event recovered interest on the test trials if the contact relation changed (from contact to no contact, or vice versa); the infants did not respond to a contact change in a reach event. When the hand was replaced by an inanimate object, infants did not recover interest to a contact change for either pick-up or reach events. Taken together, these results suggest that 7-month-olds see an event in which a hand and an inanimate object move together as a *causal* interaction and attend to contact relations between the hand and the object: An event in which two inanimate objects moved together equivalently was not perceived as a causal interaction.

Two recent studies further explored infants' representations of the entity playing the agentive role in a causal interaction. Pauen and Trauble (2006) let 7-month-old infants watch an ambiguous motion event, in which a ball attached to a furry animal-like tail bounced and rolled erratically around a small stage. Because both the ball and the tail always moved together, they could not assign causal roles based on spatiotemporal cues. Then, the ball and the tail were separated and laid stationary in separate parts of the stage. Although the infants' exposure to the two objects (ball and tail) moving was equivalent and ambiguous, the looking behavior to the stationary objects was asymmetrical. Infants looked preferentially at the tail, as if they expected the tail, but not the ball, to continue to move following separation. Pauen and Trauble's data suggested that when two entities moved together, 7-month-old infants parsed the spatiotemporally ambiguous-motion event into a causal interaction based on cues to *dispositional* agency. The infants assigned the furry tail (a more plausible agent in the enduring, dispositional sense) to the agentive role—just as adults do with the same stimuli.

Saxe, Tenenbaum, and Carey (2005) found that observed motion of an inanimate object lead slightly older infants (10- and 12-month-olds) to form expectations even about an *invisible* agent. Infants were first familiarized with a stationary beanbag, enabling them to assign it the stable dispositional property of being inert. Infants were then habituated to a live-action event in which the beanbag was thrown over a wall, onto a stage. The beginning of the event was hidden; the beanbag emerged already in motion. Although only the beanbag was visible, adults perceived this event as the beanbag "being thrown" by a person located beyond the wall. On test trials, after the beanbag landed, a live human hand emerged from one side of the stage: either the side from which the beanbag came (the "same" side) or from the opposite side (the "different" side). Ten- and 12-month-old infants differentiated these two types of test trials. They looked significantly less at a hand that suddenly appeared on the stage on the same side—consistent with the hand having thrown the beanbag—than they looked at a hand emerging from the different side. We suggested that infants looked longer at a hand emerging on the different side of the stage, because that position was inconsistent with the agentive role.

In a control experiment, the human hand was replaced by a brightly colored toy train. Infants looked equally long no matter from which side the train came. Furthermore, if previously familiarized with a self-moving puppet, which then replaced the beanbag in these same events, infants did not expect a hand to emerge from the side of the stage from which the puppet had emerged.

Thus, infants appeared to expect an agent in the agentive role of an interaction with the beanbag, even though no agent (and no interaction) was visible. These results suggest that (a) infants expect, and infer the existence of, an agent as the source of motion of an inert object; and (b) infants recognize a human hand, but not a toy train, as a possible agent. The present studies extend our previous results to new events and new control objects. In addition, our studies (a) explore a complimentary inference to that explored in the previous studies (using a representation of the agent to predict the effect, as well as using the effect to infer the agent); (b) investigate these inferences in even younger infants (7-month-olds), nearing the age of the earliest demonstrated sensitivity to the causal structure of events; and (c) begin to explore the features that lead infants to assign a novel entity the status of a dispositional causal agent.

Experiment 1

Our interpretation of our previous study was that 10- and 12-month-old infants use the motion of an inanimate object to form expectations about the existence and position of the human hand that caused that motion. If this is so, infants should make a complementary inference: They should use the position of a human hand to form expectations about the motion of an inanimate object, even if the causal interaction itself cannot be seen.

The idea of Experiment 1 was simple. Infants were habituated to two potential causal effects: On different habituation trials, a yellow beanbag emerged from behind a screen on the right, or a red beanbag emerged from behind a screen on the left. At test, infants were first shown what was behind each screen (the potential causal agents): a hand on one side and a train on the other. Then the screens were raised, occluding the agents, and a beanbag was thrown from one side. If the infants understand that hands can cause the motion of inert objects but trains cannot, then they should look longer when the beanbag emerges from the side the train was on (the unexpected event).

The current design offered substantial improvements over our previous paradigm. First, Saxe et al. (2005) used a between-subjects design: Different groups of children saw a hand or a train in the test trials. Here, the hand and the train were revealed on every trial: Whether the outcome was expected or not depended on the match between the position of the hand and the emergence of the beanbag. Second, the motion parameters of the hand and train in Saxe et al. (2005) were slightly different: The train ran along the floor of the stage, while the hand (and arm) emerged in mid-air and the hand moved slightly faster than the train. Here, both were stationary during the test trials. Finally, although the hand experiment was conducted with 10- and 12-month-olds, only 12-month-olds participated in the train control condition. In Experiment 1, we eliminated these methodological concerns by revealing the stationary hand and control object simultaneously on every test trial, for every infant.

In our previous experiments, looking time on the test trials was measured in response to the emergence of a completely novel entity—a live human hand—that the infants had never seen before in the experimental setting. It is not surprising that all infants recovered interest when the hand first appeared. Consequently, the influence of the causal inference on the infants' looking times was superimposed on a large nonspecific effect of simple novelty. In the present study, at the time we measured looking, the test event was identical to the habituation events. Therefore infants' looking times on the test trials may be influenced mainly by the causal inference and not by novelty, allowing a cleaner test of our hypothesis.

Method

Twenty 9.5-month-olds participated (11 boys; mean age 9 months 14 days; range 9 months 3 days to 10 months 7 days). Families were approached by letter from birth records and received a token gift for participation. An additional 3 infants were excluded because of fussiness. Infants were recruited from a database of local families who had expressed interest in the research. Averaged across all three experiments, the infants were 70% White, 5% Asian, and 25% unreported or other, according to a voluntary parental questionnaire. Information about parental education or socioeconomic status was not available.

All events were created live on a black stage 2 feet (0.61 m) in front of the infant (17 in. × 34 in. [43.18 cm × 86.36 cm]). The stage was covered by a black board that could be raised to reveal the stage. At the extreme right and left sides of the stage, about 4 in. (10.16 cm) back from the front edges, were two upright bright orange screens, about 5 in. (12.70 cm) square. Between the two screens, lying on the stage floor, was a square white cloth about 4 in. (10.16 cm) square.

Infants were placed in a high chair in a darkened experimental room, facing the brightly lit stage. Their mother sat next to them, facing the infant (and away from the stage). The child's looking at the stage was recorded by a camera and fed to an online coding monitor in a different room; the coder was completely unaware to the experimental condition. Trial endings, determined by a 2-s look-away criterion, were signaled by a computer beep. A second camera recorded the events on the stage for subsequent analysis of any possible experimental error.

At the start of the experimental session, two beanbags (one red and one yellow) were revealed, lying stationary on the stage for 20 s. This exposure provided spatiotemporal evidence that there were two beanbags and that they were inert, inanimate objects. Following this exposure, babies were shown habituation/familiarization trials. On each trial, the screen was raised and either the red bean bag was thrown from behind the right screen or the yellow beanbag was thrown from behind the left screen, onto the white cloth in the center of the stage (see Figure 1). Trials were presented in a fixed, pseudorandom sequence, so that it was not possible for the child to predict, on a given trial, which beanbag would be thrown. Looking time was coded from the moment the beanbag landed; when the trial ended, the screen covering the stage was lowered. These events were repeated until

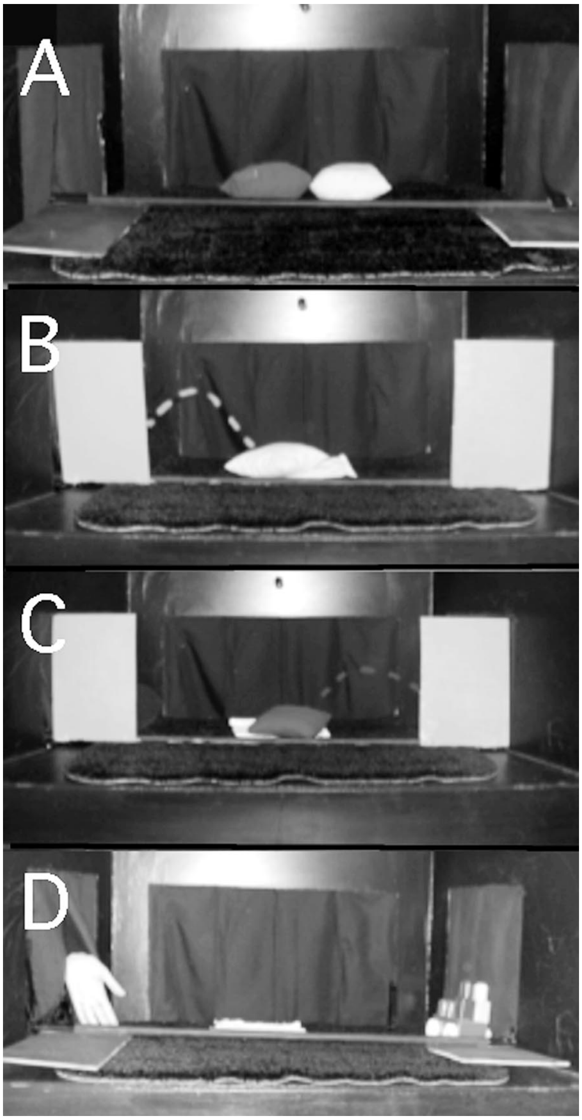

Figure 1. Trial structure for Experiment 1. A: Infants were familiarized to 2 beanbags lying stationary on the stage for 20 s. B: On each habituation trial, one of the beanbags was thrown either from the left, or (C) from the right. D: On test trials, the screens rolled down to reveal a hand on one side and a train on the other. Then the screens were raised, and a beanbag emerged either from the hand side (as in B) or from the train side (as in C).

the infant habituated (average looking time on 3 successive trials less than half of the average from the first 3 trials), to a maximum of 12 trials.

After the habituation criterion was met (or after a total of 12 habituation trials), 4 test trials commenced. On each, the stage opened to reveal the same upright orange screens. Then the orange screens rotated forward and down, so that the infants could see what was behind them. Behind one screen was a stationary live human right hand (palm up, fingers forward), and behind the other screen was a toy train (see Figure 1). The screens remained down for 8 s and then rotated up again. Immediately thereafter, a beanbag was thrown from behind one screen, as on the habituation trials. The hand and train remained on a given side for consecutive pairs of test trials (1 and 2 vs. 3 and 4), and the side of emergence of the beanbag switched (1 and 4 vs. 2 and 3), so that expected and unexpected trials alternated. Counterbalanced across infants were whether the first trial was expected or unexpected and whether the hand was on the left or the right on the first pair of test trials. Twenty-five percent of infants were recoded by an independent observer; interobserver reliability was 93%.

Results and Discussion

Overall looking time decreased significantly from the first 3 (average 9.4 s) to the last 3 trials (average 5.9 s, $p < .01$, paired-samples t test), suggesting that the infants were encoding the habituation trials. The average number of habituation trials per infant was 10.3. Eight infants failed to meet the habituation criterion in 12 or fewer trials. Planned contrasts indicated that infants who did not habituate looked significantly less than the other group on the first 3 habituation trials, $t(15.7) = 3.30$, $p < .005$ (equal variances not assumed), but equally on the last 3 habituation trials, $t(12.5) = -0.12$, *ns*, suggesting that these infants were less engaged in the experiment from the beginning, rather than that 12 trials was not enough time to encode the habituation events.

As can be seen in Figure 2, infants looked longer overall at the test trials in which the beanbag emerged from the train side ($M =$ 8.3 s) than from the hand side (5.7 s, $p < .05$, paired-sample t test). Fourteen out of 20 infants showed this pattern of longer looking when the beanbag emerged from the train side ($p < .05$, one-tailed, sign test).

A four-way analysis of variance (ANOVA) examined the effects of habituation criterion (reached or not reached), trial type (hand side or train side), test pair (first or second), and order (hand side first or train side first) on looking times during the test trials. There were no significant main effects or interactions involving either test pair or order. The only significant effects were a weak main effect of trial type (infants look longer when the beanbag comes from the train side), $F(1, 16) = 3.34$, $p < .10$ ($\eta = .17$), and a strong interaction between trial type and whether the infant reached the habituation criterion, $F(1, 16) = 6.95$, $p < .01$ ($\eta =$ .30).

Separate ANOVAs were therefore conducted to examine the effects of trial type, pair, and order in the infants who did and did not reach the habituation criterion. Eleven of the 12 infants who did habituate also looked longer at the unexpected train-side test trials than at the hand-side trials ($p < .05$, sign test). These infants showed a significant main effect of trial type, $F(1, 10) = 8.40$, $p <$ .02 ($\eta = .46$), and no other main effects or interactions. By contrast, only 3 of the 8 infants who did not habituate looked longer at the unexpected trials overall. These infants showed no main effects or interactions at the test trials.

A final analysis examined the difference in looking time to the last three habituation trials and the first pair of test trials. Given the effects of reaching habituation criteria revealed in the previous analysis, we analyzed the two groups of infants (those who met habituation criterion and those who did not) separately. As can be seen from Figure 2, infants who had not met the habituation criterion did not dishabituate on either type of test trial [first train-side trial > last three habituation trials, $t(6) = 0.03$, *ns*; first hand-side trial > last three habituation trials, $t(6) = 0.06$, *ns*]. Those who did meet habituation criterion dishabituated to the first train-side trial, $t(10) = 2.75$, $p < .05$, and generalized habituation

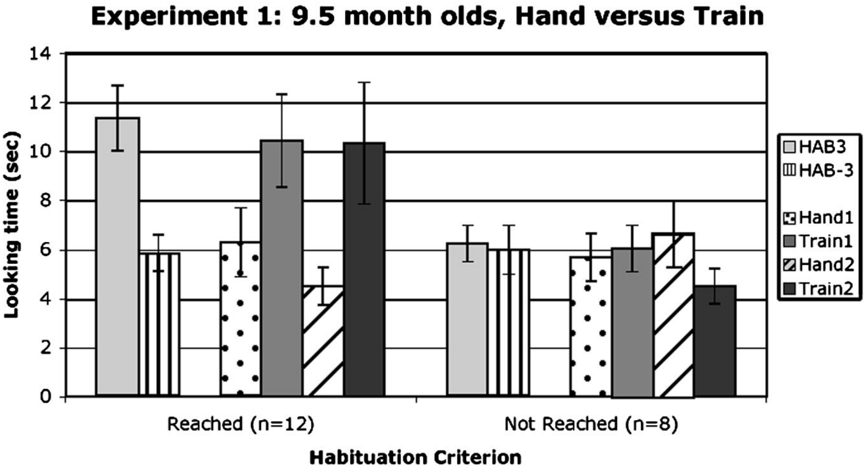

Figure 2. Results of Experiment 1. Average looking time (in seconds). Nine-and-a-half-month-old infants recovered interest when the beanbag came from the train side but not when it came from the hand side. This effect was due entirely to the infants who did habituate (left section); there was no effect of trial type for infants who did not habituate (right section). HAB3 = average of the first three habituation trials; HAB-3 = average of the last three habituation trials. Bars show standard error.

to the first hand-side trial, $t(10) = 0.80$, *ns*. Thus, although infants had never seen the hand and the beanbag interact, they considered the beanbag likely to come from the hand side of the stage and not from the train side. These results are consistent with those of Saxe et al. (2005): Both studies suggest that by 10 months of age, infants treat a live human hand, but not a toy train, as a likely cause of the motion of an inanimate object.

Experiment 2

Experiment 1 leaves open the question of exactly which features of the hand infants use to identify a causal agent. The child may simply represent hands, per se, as causal agents of throwing events. That is, the causal knowledge deployed in this task may be specific to hands and to throwing; in the child's experience, hands throw and trains do not. Alternatively, it may be the mechanical affordances of a hand as a potential device for throwing that makes a hand a better candidate for the source of motion of a beanbag than a toy train or block. Or, it may be the capacity of the hand for self-generated motion or for intentional goal-directed action that does so. Of course, these are not mutually exclusive possibilities: Hands might be represented in terms of each of these dispositional properties, and each could contribute to constraining the causal interpretation of a specific event. As a first test of these hypotheses, in Experiment 2 we replaced the human hand with a novel agent: a small furry puppet.

The design of Experiment 2 exactly followed that of Experiment 1, except that when the two potential causal agents were revealed behind the two screens at the beginning of the test trials, the toy train was on one side and a puppet (see Figure 3) on the other. The puppet had properties common to intentional agents (eyes, fur, self-propulsion), but did not have the mechanical affordances for throwing a beanbag (no arms, and the puppet was approximately the same size as the beanbag) and had never been seen throwing anything. If the knowledge of hands as causal agents is specific to hands (and to throwing) or if infants conduct an online analysis of mechanical affordances, then the puppet would be a poor candidate for the cause of the beanbag's motion. In contrast, if infants recognize cues to dispositional agency, then the puppet may be a more likely causal agent than the train.

Figure 3. Trial structure for Experiment 2 was identical to Experiment 1, except for the use of the novel puppet.

Method

Twenty 9.5-month-olds participated (11 boys; mean age 9 months 20 days; range 9 months 12 days to 9 months 29 days). An additional 3 infants were excluded: 2 because of fussiness and 1 because of parental interference. The experimental set-up was identical to that of Experiment 1, with one exception. On test trials, the human hand was replaced by a furry brown marionette (3.5 in. × 3.5 in. × 5 in. [8.89 cm × 8.89 cm × 12.70 cm]). Before the experiment began, infants were familiarized with the puppet: For 20 s, the puppet jumped slowly across the bare stage. The puppet hung from black threads, invisible against the black background and was controlled by the experimenter from above so that its motion appeared self-propelled. All other parameters of the experiment remained the same as in Experiment 1, except the infants were not familiarized with the beanbags prior to the habituation trials. The behavior of the beanbags during the habituation trials provides ample evidence that they are dispositionally inert—they remain motionless after landing and they have no morphological cues of self-moving entities. Twenty-five percent of infants were recoded by an independent observer; interobserver reliability was 96%.

Results and Discussion

The data are plotted in Figure 4. Overall looking time decreased significantly from the first 3 (average 8.2 s) to the last 3 trials (average 5.4 s, $p < .05$, paired-sample *t* test), suggesting that the infants were encoding the habituation trials. The average number of habituation trials per infant was 9.2. Eight infants failed to meet the habituation criterion in 12 or fewer trials. As in Experiment 1, infants who did not habituate looked less long than the other infants on the first 3 habituation trials, $t(14.1) = 3.20$, $p < .01$ (equal variances not assumed), but equally on the last 3 habituation events, $t(9.2) = 1.60$, *ns*, suggesting that these infants were less engaged in the experiment from the beginning, rather than that 12 trials was not enough time to encode the habituation events.

The infants looked longer overall at the test trials in which the beanbag emerged from the train side ($M = 7.2$ s) than from the puppet side (5.1 s, $p = .05$, paired-sample *t* test). Fifteen out of 20 infants showed this pattern of longer looking when the beanbag emerged from the train side ($p < .05$, Sign test). Planned contrasts revealed that infants looked significantly longer at train-side than puppet-side trials on the first pair of test trials, $t(19) = 2.70$, $p < .05$, but not on the second pair, $t(17) = 0.40$, *ns*.

A four-way ANOVA examined the effects of habituation criterion (reached or not reached), trial type (puppet side or train side), test pair (first or second), and order (hand side first or train side first) on looking times during the test trials. There were no significant main effects or interactions involving order; therefore, this variable was removed from the analysis. The only significant effects were an interaction between test trial type and test trial pair, $F(1,16) = 4.39$, $p = .05$ ($\eta = .22$), and an interaction between test trial pair and whether the infant reached the habituation criterion, $F(1, 16) = 6.16$, $p < .05$ ($\eta = .28$).

Separate ANOVAs were therefore conducted to examine the effects of test trial type and pair in the infants who did and did not reach the habituation criterion. Nine of the 12 infants who did habituate also looked longer at the unexpected train-side test trials

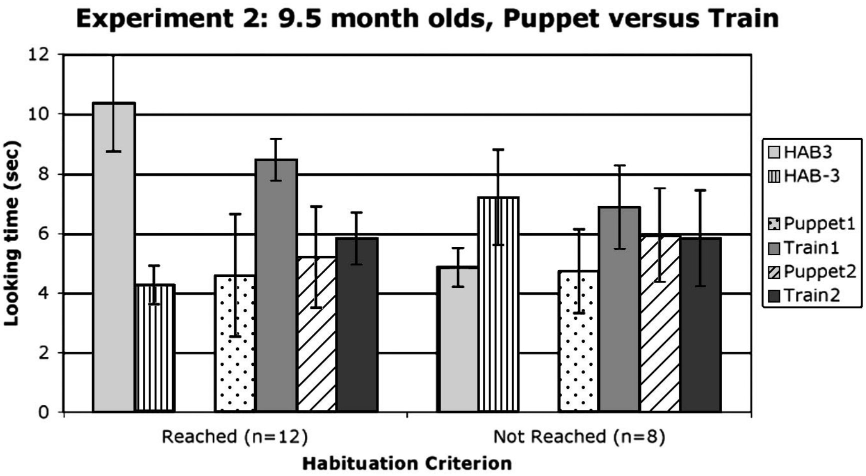

Figure 4. Results of Experiment 2. As in Experiment 1, 9.5-month-old infants recovered interest when the beanbag came from the train side but not when it came from the puppet side. This effect was due entirely to the infants who did habituate (left-hand side); there was no effect of trial type for infants who did not habituate (right-hand side). HAB3 = average of the first three habituation trials; HAB-3 = average of the last three habituation trials. Bars show standard error.

than at the puppet-side trials. These infants showed a significant interaction of Trial Type × Pair, $F(1, 11) = 5.50$, $p < .05$ (η = .33), reflecting that these infants looked longer at the train-side trials on the first pair of test trials. There was also a main effect of test pair, $F(1, 11) = 5.55$, $p < .05$ ($\eta = .44$), because these infants looked less long overall on the second pair of test trials. Planned comparisons indicated that the infants in this group looked longer at the train-side trials on the first pair, $t(11) = 2.3$, $p < .05$, but not on the second pair, $t(10) = 0.45$, *ns*. Of the 8 infants who did not habituate, 5 looked longer overall at the unexpected test trial (see Figure 4). There were no significant main effects or interactions of test trial type or pair in these infants.

To compare these results directly with those of Experiment 1, we conducted a three-way ANOVA to examine the effects of trial type (train-side vs. agent-side), habituation criterion (met vs. not), and agent candidate (hand vs. puppet). There was a significant main effect of trial type, $F(1, 36) = 7.32$, $p < .01$ ($\eta = .17$), and a significant interaction with habituation behavior, $F(1, 36) = 4.75$, $p < .05$ ($\eta = .12$). There was no interaction between trial type and agent candidate, $F(1, 36) = 0.001$, *ns* ($\eta = .00$), although there was a trend toward a three-way interaction between trial type, habituation behavior, and agent candidate, $F(1, 36) = 3.16$, $p < .10$ ($\eta = .08$), indicating that the difference between infants who did and did not habituate was more pronounced in the hand group than in the puppet group.

Finally, looking times on the last three habituation trails were compared with those on the first pair of test trials. As in Experiment 1, infants who had reached habituation criterion generalized habituation to the train-side test trial, $t(11) = 0.4$, *ns*, but there was a trend for these infants to dishabituate on the first puppet-side test trial, $t(11) = 1.9$, $p = .08$. Those who had not reached habituation criterion differentiated neither test event from their last three habituation trials, both $t\text{s}(7) < 1.4$, *ns*.

These results replicate and extend the results of Experiment 1, using a novel causal agent: a self-propelled furry puppet. Although the puppet was not a hand and did not have the mechanical affordance to throw the beanbag, 9.5-month-old infants identified the puppet as a more likely causal agent of the beanbag's motion than the toy train. Note that both the train and the puppet were present on every test trial but that neither the train nor the puppet was visible when we recorded infants' looking at the beanbag. Therefore, infants must have attended to the relationship between the previously perceived location of the candidate causal agent and the *source* of the subsequently perceived beanbag's motion.

The two-screen paradigm provided three methodological advantages over our previous design: (a) Both the hand/puppet and train test objects were presented to each infant on each test trial, allowing a fully within-subjects design; (b) the hand/puppet and train were stationary throughout the trials, eliminating any possibility that infants discriminated between the test trials based on the different motion parameters of the test objects; and (c), the ends of the test trials, when looking time was recorded, were visually identical to the habituation trials.

Notice, however, that the inference in Experiments 1 and 2 was conceptually simpler than that tested in our previous experiments. First, the test trials in Experiments 1 and 2 preserved the temporal order of causal interactions: Infants first saw the potential causal agents and then saw the causal effect (the motion of the bean bag). As a consequence, these experiments required infants to make an inference about a causal relationship they did not see, but it was a causal relationship between two entities both of which had been seen, albeit never concurrently. In Experiment 3, we adapted the two-screen paradigm to test the more sophisticated inference investigated in our previous studies: using motion of an inanimate object to infer the position of a never-before-seen causal agent.

Experiment 3

In Experiment 3, as in our previous studies (Saxe et al., 2005), infants were habituated to a single beanbag flying into view, in this case from inside a box. Two boxes were placed on the stage, and a red beanbag was thrown out of one box into the center of the stage on every trial. At test, after the beanbag was thrown out, the front panels of both boxes were lowered to reveal a human hand in one box and an inert object in the second box. If infants infer an agent as the ultimate cause of the beanbag's motion, then they should look longer when the beanbag's box of origin contains an inert object than when it contains a human hand (the inferred agent). This design allowed us to probe infants' expectations about the identity of the causal agent directly, after the event. As in Experiment 1, though, the hand and control objects were completely stationary and were presented simultaneously on every test trial. Also, in Experiment 3 we included for the first time a group of younger infants: 7-month-olds.

Method

Sixteen 10-month-olds (11 boys, 5 girls; mean age 9 months 28 days; range 9 months 21 days to 10 months 18 days) and sixteen 7-month-olds (11 boys, 5 girls; mean age 7 months 2 days; range 6 months 19 days to 7 months 15 days) participated in Experiment 3.

Babies were familiarized with the red beanbag by direct handling prior to entering the experimental room. The stage was set up as in Experiment 1, with one exception: In place of the black board, the stage was occluded by a red curtain that opened from the center.

On each habituation trial, the curtain opened to reveal two boxes, one pink and one yellow, sitting upstage. Each box was 5 in. (12.70 cm) tall, 4 in. (10.16 cm) wide, and 6 in. (15.24 cm) deep, and had an open top. The red beanbag was thrown out of one box into the space between the two boxes (the center of the stage; see Figure 5). The box of origin of the beanbag was kept constant for each infant but was counterbalanced across infants. Infants could not see the source of the beanbag's motion inside the box. Looking time was measured from the time the beanbag landed on the stage. When the infant looked away from the stage for at least 2 s, the trial ended and the curtain closed. Habituation trials were shown either until the infant habituated or until the infant had seen a total of eight habituation trials. (A smaller maximum of habituation trials was used, because in pilot studies we found that the younger children tended to fuss out after more than 12 total trials; the habituation events in Experiment 3 should have been simpler to encode because the very same event occurred on every trial.)

Test trials began with the same event as the habituation trials. After the beanbag landed, the front walls of both boxes rotated forward, revealing a stationary bare human hand (palm forward, fingers down) in one box and a brightly colored block (covered in polka dots and sparkles) in the other box. Each infant saw four test trials. On alternating trials, the hand appeared either in the box from which the beanbag was thrown (same-side trials) or in the other box (different-side trials; see Figure 5). The order of test trials was counterbalanced across infants. Looking times were measured from the opening of the boxes.

Results and Discussion

The results are shown in Figure 6. The average number of habituation trials per infant was 7.3; three 7-month-olds and five 10-month-olds habituated in eight or fewer trials. The 10-month-old subjects looked less long on the last three habituation trials (average 4.46 s) than on the first three (6.08 s, $p < .03$, paired-sample t test). By contrast, the 7-month-olds as a group showed no hint of habituation, looking if anything longer on the last three (7.47 s) than on the first three habituation trials (5.65 s, *ns*).

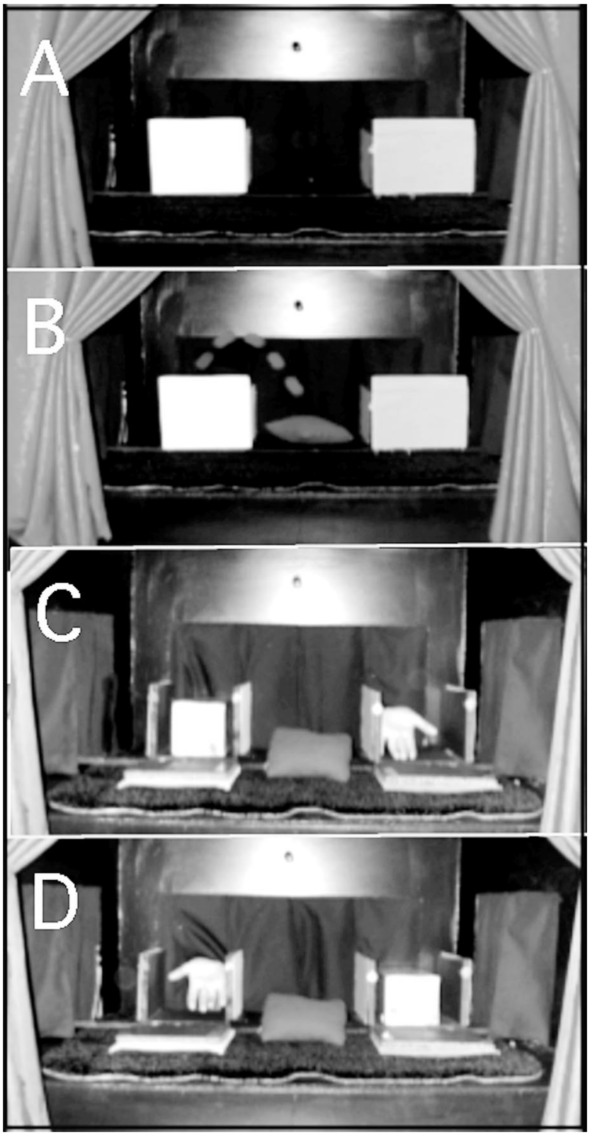

Figure 5. Trial structure for Experiment 3. A: The beginning of each trial. Infants were familiarized with the beanbag prior to entering the experimental room. B: On every trial, the red beanbag was thrown out of one box. The box of origin of the beanbag was kept constant for each infant. C: On "unexpected" test trials, the boxes were opened to reveal a hand in the "different" box from the box of origin of the beanbag, and a colored block in the "same" box. D: On "expected" test trials, the hand was in the "same" box.

Nevertheless, the two age groups performed similarly on the test trials. Twelve of sixteen 10-month-olds and twelve of sixteen 7-month-olds looked longer overall at the unexpected test trials (both ps $< .05$, sign test). An ANOVA examined the effects of age (7- or 10-month-olds), habituation criterion (reached or not reached), test trial type (hand in same side or different side), and order of test trials (same-side first or same-side second) on the average looking times during the test trials. There was the predicted main effect of trial type (longer looking at different-side than same-side trials, $F(1, 24) = 8.57$, $p < .01$ ($\eta = .26$), and no

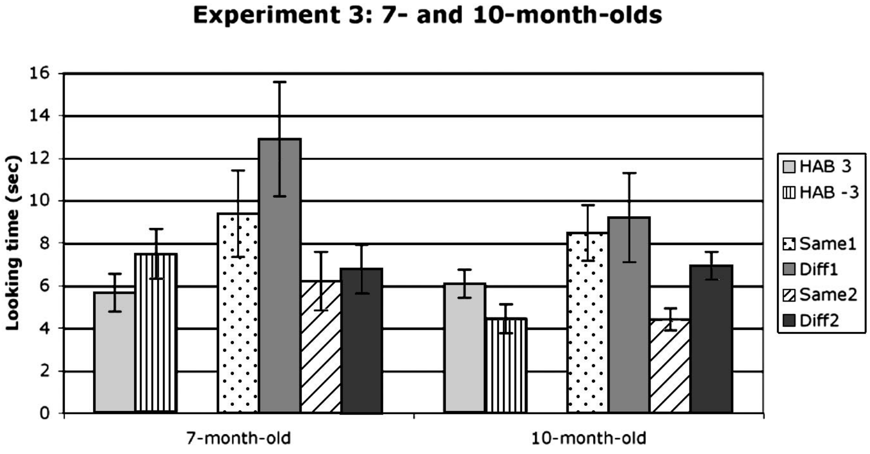

Figure 6. Results of Experiment 3. Average looking time (in seconds). Ten-month-old infants looked significantly longer when the hand was on the "different" side (right-hand side). Seven-month-olds also looked longer at the hand on the "different" side (left-hand side). HAB3 = average of the first three habituation trials; HAB-3 = average of the last three habituation trials. Bars show standard error.

interaction between trial type and age. However, the main effect of trial type was mediated by an interaction with order, $F(1, 24) = 18.32$, $p < .01$ ($\eta = .43$), and by a three-way interaction between trial type, order, and habituation, $F(1, 24) = 9.45$, $p < .01$ ($\eta = .28$). These interactions reflect an unexpected pattern: The effect of order (i.e., looking longer at the first test trial) was stronger in the infants who did habituate than in infants who did not.

Separate ANOVAs were then conducted for each age group to examine the effects of trial type and order. The results for the 10-month-old infants were simple: The older infants looked longer at the different-side than at same-side trials, $F(1, 14) = 4.50$, $p = .05$ ($\eta = .24$). There was no main effect or interaction with order. Separate post hoc *t* tests showed that this effect was significant on the second pair of test trials, $t(15) = 3.34$, $p < .005$, but not on the first pair, $t(15) = 0.50$, *ns*. In the younger infants, there was also a main effect of trial type, $F(1, 14) = 5.09$, $p < .05$ ($\eta = .27$), but this was mediated by an interaction with order, $F(1, 14) = 6.71$, $p < .05$ ($\eta = .32$), and a main effect of order, $F(1, 14) = 11.34$, $p < .01$ ($\eta = .45$). These effects reflected the following pattern of data: (a) 7-month-olds who saw a different-side (unexpected) test trial first looked longer at the different-side test trials, but they also looked longer at the test trials overall (main effect of order); and (b) those 7-month-olds who saw a same-side test trial first looked equally at same- and different-side test trials (interaction of order and trial type) and looked less long overall.

In all, the results of Experiment 3 confirm that 10-month-old infants infer a hidden agent as the source of motion of an inanimate object. When shown a beanbag emerge repeatedly from a box, the infants pay more attention if a hand is revealed in a different box (inconsistent with the agentive role) than if it is revealed in the same box from which the beanbag was thrown. On every test trial both a hand and a salient control object were present; that infants differentiated the test trials shows they represented a relationship between the hand and the source of motion of the beanbag.

Even the younger group in our study, 7-month-olds, appear to already make the same inference, although these results must be interpreted with some caution because (a) the younger infants did not habituate, suggesting that they encoded the habituation trials differently from the older infants; and (b) the effect of test-trial type was mediated by order in the younger children. Of the younger infants, only those who saw the unexpected trial first looked longer at the unexpected trials, consistent with a more fragile representation of causal agency in the younger group.

General Discussion

Experiments 1 and 3 provided convergent data to those from Saxe et al. (2005), supporting the conclusion that 7- to 10-month-old infants consider a human hand more likely than a toy train or block to be the cause of an inanimate object's ballistic motion, and these results were extended to a novel causal agent in Experiment 2. In Experiment 1, 9.5-month-old infants used the position of a hand, but not a train, to predict the motion of a beanbag. In Experiment 2, 9.5-month-old infants did the same for the contrast of a puppet versus a train. In Experiment 3, 10- and 7-month-old infants used the motion of a beanbag to predict the location of a hand, but not a colored block. In both cases, the test objects (hand vs. train or block) were stationary throughout the experiments and were presented simultaneously on every test trial.

These studies concern how young infants use the enduring causal properties or dispositions of an entity to form expectations about its role in a specific causal interaction. Previous research suggested that infants' expectations about a causal interaction depend on the dispositions of the entity in the receptive role. For example, Baillargeon and colleagues (e.g. Kotovsky & Baillargeon, 2000; Wang et al., 2003) found that when the entity in the receptive role was categorized as inert, infants' attention was drawn if it appeared to (a) resist motion when hit by another object, (b) spontaneously move without external contact, or (c) move through the air without support. These expectations were reversed when the entity in the receptive role was previously categorized as a self-moving agent (described in Kotovsky & Baillargeon, 2000). Similarly, Saxe et al. (2005) found that infants expected an external ultimate cause for the motion of an inert beanbag, but not for the motion of a puppet previously seen to be self-moving. As Baillergeon and colleagues have argued (Kotovsky & Baillargeon, 2000; Wang et al., 2003), once an entity has been categorized as inert or self-moving, this categorization is maintained and influences representations of subsequent interactions.

The present data, along with those from Saxe et al. (2005), suggest that an analogous argument can be made for the entity in the agentive role of an interaction. Once entities are categorized according to enduring causal dispositions (inert objects vs. causal agents), infants appear to use this categorization to determine which entity is most likely to play the agentive role in a (subsequent) specific interaction. Thus, once infants in Experiment 1 saw a hand on one side of the stage, and a train on the other, the infants expected a beanbag to emerge (following an inferred causal interaction) from the side of the hand (the more likely causal agent). Similarly, once infants in Experiment 3 saw a previously categorized inert object (the beanbag) emerge repeatedly from inside a box, their attention was drawn if a hand (the more likely causal agent) was revealed in a different box.

Experiment 2 began to explore which features of the hand infants use to identify a causal agent. Observation of the furry, googly eyed, spindly legged, self-moving puppet apparently led infants to represent it as a candidate dispositional agent. Subsequently, infants treated it as they treated the hand in Experiment 1—they took it as a better candidate cause of the beanbag's motion than was the train. Thus, the representations of dispositional agency relevant to this inference are not limited to representations of hands as throwers or to the mechanical affordances of hands as throwers. Of course, we do not know whether the animal-like morphological features, self-motion, or both were the relevant cues. Ongoing research in our laboratory is exploring the specific cues to dispositional agency that infants exploit.

The data from the youngest infants bear replication, given their failure to habituate and the significant effects of test-trial order on their looking times. Still, 7-month-olds as a group were just as likely to differentiate the test trials based on the match between the position of the hand, and the motion of the beanbag, as were 10-month-olds. If replicated, these results may be particularly significant. Most current theories of how infants perceive causality and intentional action posit a purely perceptual categorization mechanism for detecting agents among the visible entities in a scene, especially for young infants (e.g., Kosugi et al., 2003; Meltzoff & Moore, 1994; Pauen & Trauble, 2006; see also Csibra, Gergely, Biro, Koos, & Brockbank, 1999). The assumption has been that, unlike adults, infants could not form expectations about entities that they had never seen, or could only build such expectations following extensive perceptual experience. The current data undermine that assumption. Around the same age that infants first distinguish between the agentive and receptive roles in fully visible causal interactions (Cohen et al., 1998; Leslie & Keeble, 1987; Pauen & Trauble, 2006), and not long after infants first distinguish between visible agents and inert objects in their capacity for goal-directed action (Woodward, 1998), 7-month-old infants can infer the existence of an agent that makes its presence known solely through its effects on other objects.

In addition to revealing flexibility and sophistication in infants' causal reasoning, these experiments bear on the infants' concept of an agent. According to the recent and influential "teleological" model of Gergely and Csibra (1997), infants classify specific events as instances of rational action, based on properties like equifinality (a common endpoint), without ever categorizing entities according to enduring dispositions, into agents (to whom goals can be attributed) and inanimate objects (to which they cannot). Gergely and Csibra contend that a "goal" is attributed to the action itself and not to any entity (Csibra at al., 1999).

We take our data, along with those of Saxe et al. (2005), to cast doubt on this agentless teleological model. In events designed to emulate Csibra et al. (1999), infants do distinguish between agents (to whom ultimate causal power can be attributed) and inanimate objects (to which it cannot). It seems likely that a goal to throw the beanbag (out of the box, or over the wall) is attributed to the inferred agent in our studies, along with the causal power to realize that goal. However, further experiments will be required to establish this interpretation and more generally to probe the relationship, in the infants' minds, between the ontological categories of *causal agent* and *intentional agent*.

What is already clear is that preverbal infants make the ontological distinction between agents and inanimate objects and can use this distinction to make predictions for subsequent specific causal interactions that depend on the enduring causal dispositions of the entities in both the agentive and receptive roles. In particular, infants seem to expect that there is an agent in the ultimate agentive role of any interaction.

This expectation persists through development. Indeed, during early childhood the inference of unseen agents may be overgeneralized, leading to young children's "promiscuous teleology" (Kelemen, 1999). Elementary school-age children invoke an (unseen) agent designer to explain the origin of most objects and events, like the child who said that the "first ever" river existed "because probably people always put water in a big hole" (Kelemen & DiYanni, 2005, p. 30). Across cultures, adults continue to invoke an unseen agent in intuitive explanations of unusual, significant, or apparently spontaneous events (Barrett, 2004), as Margaret Mead (1932) observed among the Manus people of the Admiralty islands in 1928: "If a stone falls suddenly in the brush near an adult, he will usually mutter 'a spirit'" (p. 181).

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