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Infants' Causal Representations of State Change Events

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Abstract

Five experiments extended studies of infants' causal representations of Michottian launching events to 8-month-olds' causal representations of physical state changes. Infants were habituated to events in which a potential causal agent moved behind a screen, after which a box partially visible on the other side of the screen underwent some change (motion or state change). After habituation the screen was removed, and infants observed full events in which the potential agent either did or did not contact the box (contact vs. gap events). Infants were credited with causal representations of the events if their attention was drawn both to gap events in which the effect nonetheless occurred and to events with contact in which the effect did not happen. The experiments varied the nature of the effect (motion vs. state change) and the nature of the possible causal agent (train, hand, novel intentional agent). Both the nature of the effect and the nature of the possible agent influenced the likelihood of causal attribution. The events involving motion of the patient replicated previous studies of infants' representations of Michottian launching events: the toy train was taken as the source of the boxes motion. In contrast, infants attributed the cause of the box's physical state change to a hand and novel self-moving entity with eyes, but not to a toy train. These data address early developing causal schemata, and bring new information to bear on theories of the origin of human causal cognition.

Keywords

causality; infant cognition Michotte; state change; intentional agency

Causal representations play a very important role in human mental life: they articulate explanatory understanding and are central to the structure of language. Causal representations go beyond the sensory and spatiotemporal information available to perceivers. We can detect spatiotemporal relations among events and compute conditional probabilities among the occurrences of events, but representations of spatiotemporal relations and conditional probabilities contain no symbol *cause*. Causes cannot be seen – their representations must be provided by the mind. There is a long tradition of attempts to understand the mental faculty that provides causal representations, including attempts to account for its ontogenetic origins (within philosophical discourse, see for example, Hume, Kant; within psychology, see for example, Cohen, Amsel, Redford, & Casasola, 1998; Cohen & Oakes, 1993; Gopnik & Schulz, 2007; Leslie, 1995; Michotte, 1963; Newman, Choi, Wynn, & Scholl, 2008; Piaget, 1954).

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Accounting for the origin of the capacity for causal representations requires answering three distinct, partly orthogonal, questions. First, one must characterize the nature of causal representations, and characterize the process that leads a causal relation among events to be posited. Although a full analysis of the nature of causal representations falls outside of the scope of this paper, we assume a version of a “difference making” analysis widely accepted in the philosophical literature (e.g., Woodward, 2003; see also Gopnik and Schulz, 2007). Causal relations are those that support certain counterfactuals; if not for the cause, the effect would not happen; if the causal prerequisites are met, the effect will happen. Second, one must discover the earliest specific causal relations among events or states of the world infants actually represent – what are the earliest causal schemata? Much research on young infants’ causal representations has concerned one particular causal scheme—Michottian launching events. The present experiments expand the focus of study from representations of events in which a situational agent is seen as a cause of an entity’s motion to representations of events in which a situational agent is seen as the cause of an entity’s physical state change. Discovering which causal schemata infants represent will in turn constrain, the answer to the third question – what developmental processes underlie the capacity for creating *any* causal representations at all? Are the representational resources that compute causal representation innate, or, if learned, how may they be so?

There are two traditions within which infant causal representations are studied, one deriving from the work of Michotte (1963) and one from the work of Piaget (1954). Each of these thinkers had different ideas about the nature of early causal representations, as well as of the earliest causal schemata actually formed by infants. Michotte hypothesized that causality is represented in terms of a transfer of motion, energy, momentum, or force (these concepts are not differentiated in primitive causal representations) from a situational agent to the affected entity, the situational patient. Michotte studied the psychophysics of directly perceived causality, making several discoveries that have largely stood the test of time. First, the causal relations between some moving objects are directly perceived, and are partly encapsulated from top-down knowledge. Second, causal perception in this sense is sharply limited in two respects – first, with respect to input: to a first approximation the input to these representations is limited to the spatiotemporal relations among the events and, second, with respect to domain: the domain of perceived causality is limited to motion events.

This work led Michotte to developmental hypotheses that he endorsed but did not test. He hypothesized that the capacity to form causal representations of motion events is innate, and is the root of all later developing causal representations. The developmentally earliest causal schemata, on his view, must be those involving motion events: launching, entraining and expulsion. Modern researchers exploring infant representations of Michottian causality differ as to whether the causal schemata of launching, entraining, and expulsion are innate (see Leslie’s, 1995, nativist proposal inspired by Michotte’s vs. Cohen’s and his colleague’s, 1998, arguments for contact causality being learned).

Quite apart from the question of innateness (about which we take no stand), Michotte’s theory is important today. Michottian motion events are the developmentally earliest for which there is currently positive evidence that they are seen causally, consistent with Michotte’s hypothesis concerning the original schema for causal representations. In addition, this research illustrates what is necessary to support the claim that infants represent causality at all.

Several lines of evidence suggest that by 6.5 months of age, infants represent Michottian launching events as causal. Infants are sensitive to the spatiotemporal parameters that affect adult causal perception (Cohen & Amsel, 1998; Leslie, 1982, 1984a, 1984b; Oakes, 1994). That is, they discriminate events in which the motion of a one object follows immediately upon contact with another moving object from those in which there is a spatial or temporal gap.

Furthermore, by 6.5 months of age, infants fail to discriminate among different types of interactions involving simple objects that adults see as non-causal (e.g., habituated to temporal gap events, they generalize habituation to spatial gap events), while distinguishing these categorically from those adults see as launching (Cohen & Amsel, 1998). Further, infants not only discriminate causal from noncausal motion events, but also assign roles to the individuals within the events. They are sensitive to a reversal of roles (the situational agent becomes the patient) in a typical launching event, but not to the reversal of order and direction of motion if there is a temporal or spatial gap between the motions of the objects in the events (Belanger & Desrochers, 2001; Leslie & Keeble, 1987). Altogether, these studies are consistent with the claim that by 6.5 months of age infants represent motion events as causal when one object sets another object into motion immediately on contact.

Studies on causal inferences, rather than causal perception, provide perhaps even more convincing evidence that infants represent causality in launching events. In an experiment from which the present studies take off, Ball (1973) presented infants with an occluded launching event. During habituation infants saw a stationary box (*b*), partially hidden behind a screen. Another object (*a*) entered the stage, moved behind the screen towards *b*, after which *b* began to move. This event was repeated until infants habituated to it. Importantly, the infant never saw the interaction between the two objects during habituation. The screen was then removed and infants were shown a new unoccluded test event. Half of the infants saw contact events, in which *a* contacted *b*, upon which *b* went into motion. Half of the infants saw gap events, in which *a* stopped short of *b*, at which time *b* went into motion. Ball found that infants (2 to 30 months) who viewed the gap event looked longer than infants who viewed the contact event. His interpretation was that infants represented *a* as the cause of *b*'s motion and that they saw the contact launching events, but not the gap events, as consistent with this representation (see Woodward et al., 1993, Kosugi & Fujita, 2002, for replications at 8 months of age). Thus, this study provides evidence for representations that satisfy half of the conditional relations that constitute causal representations: if *a*, then *b*. Infants' attention was drawn when the effect occurred in the absence of what they had posited as the causal conditions being met (*a*'s contacting *b*). Kotovsky & Baillargeon (2000) provided a conceptual replication of this result, and demonstrated the other half of the conditional. They also habituated infants to a hidden interaction in which the motion of a candidate situational agent was followed by the motion of candidate patient. In addition to demonstrating that infants' attention was drawn to subsequent events in which the *effect occurred* when there was no contact between *a* and *b*, they also showed that infants' attention was drawn when there *was contact* between *a* and *b*, and the effect *did not happen*. That is, the infants also found surprising those events in which the causal conditions were met and the effect did not occur.

In sum, convergent evidence from many sources suggests that by 6 to 8 months of age, infants perceive causality in Michottian launching events, and infer contact causality involving ambiguous events in which the motion of one object may have caused the motion of another. However, other recent work calls into question Michotte's hypothesis that representations of contact causality in motion events are the sole source of infants' causal cognition. Features of events beyond the spatiotemporal aspects of their interactions and trajectories influence causal attribution. The stable causal dispositional status of the potential agents and patients in motion events influences causal interpretations even at the earliest ages at which causal representations are observed at all (see Saxe & Carey, 2006, for a review). Infants' inferences about the unseen interactions between the entities behind an occluder are influenced by their representations of the dispositional status of the actors as animate agents or as inanimate objects (for launching events – Kosugi & Fujita, 2002; Kosugi, Ishida, & Fujita, 2003; Kotovsky & Baillargeon, 2000; Luo, Kaufman, & Baillargeon, 2009; Woodward, Phillips, & Spelke, 1993; for expulsion events – Saxe, Tenenbaum, & Carey, 2005; Saxe, Tzelnic, & Carey, 2007; for entraining events: Leslie, 1984b). For example, these studies show that infants infer the presence of an unseen agent if the moving figure in a motion event is a dispositionally inert entity like a bean-bag, but not if it is a self-moving figure, and that they are more likely to take a human hand or a novel self-moving agent as the situational agent in a motion event than a dispositionally inert object such as a train or a block.

These data are important for two reasons. First, that infants take causally relevant properties of the participants in events into account in their interpretations of those events provides further evidence in favor of attributing causal representations to them at all. Second, they undermine the Michottian analysis of the origin of the human capacity for causal representations. The spatiotemporal parameters that are necessary and sufficient for causal perception are not the only features infants attend to in their causal representations of events. Yet, it is possible that these properties are integrated into causal representations of motion events *after* they have developed into established causal schemata for infants – a possibility that would preserve the Michottian account. However, the fact that these properties have been found to influence 7-month-old infants' causal representations, an age very soon after infants first categorically distinguish causal and noncausal motion events, calls this alternative into question.

The present studies bring data to bear on a second aspect of the hypothesis that the earliest developing schemata for causal representations are contact causality in motion events. We extend the study of physical causality to infants' representations of state changes of inert objects, state changes that do not involve caused motion.

While casting doubt on the Michottian account of the origins of causal representations, the finding that representations of the dispositional agency of participants in events impact young infants' causal representations is predicted by the second research program concerning the origin of infants' capacity for causal representations—the Intentional Agency account. Historically, the intentional agency account derives from the work of Piaget (1954). Piaget, like Maine di Biran (see Michotte, 1963) believed that the origin of causal representations lies in our representation of our own causal agency. On this view (see White, 1995, for a modern version of this theory), causal representations originate in the context of reasoning about goal directed action, especially one's own goal directed actions. When we act on the world to achieve some goal, we often must intervene causally—to change an object's location or state. On this view, the developmentally earliest causal schemata are those involving intentional agents acting intentionally to effect changes in the world in the service of goals. Of course, as sketched, this account is not complete. Not all actions on the world actually succeed in causing the intended change; to represent causality within the Intentional Agency schema, the child infant must have some way of deciding when a causal interaction has actually occurred. In the case of physical causality (the patient is a dispositionally inert object), analyses of spatiotemporal relations and contingency must also be drawn upon.

The Intentional Agency account gains support from the data described above, in which representations of dispositional agency are shown to influence very young infants' representations of motion events. It also gains support from the massive evidence that young infants encode the behavior of other agents in terms of their goals (see Carey, 2009, for a review; Csibra, Gergely, Koos, & Brockbank, 1999, Woodward, 1998), plus the observation noted above that achieving goals often involves intervening causally.

Although the Intentional Agency account is related to Piaget's account of the origin of causal representations, in its modern versions it departs from some of Piaget's central tenets. While it is consistent with the hypothesis that infants' earliest causal representations will involve their own goal directed activity, as Piaget, White, and Maine di Biran, would all claim, it is not committed to that view. From his observations of his own infants, Piaget believed they could represent not represent other agents' causal interventions on the world until 5 or 6 months, and could not represent causal relations between inanimate entities until near the end of the second year of life.

Piaget's original formation of the Intentional Agency theory of the origin of causal representations is not tenable. The literature on infants' causal representations of Michottian launching events reviewed above shows that infants represent some interactions among inanimate objects as causal as young as 6 months of age. Still, the Intentional Agency theory predicts the data most problematic for the Michottian account – the fact that infants' causal representations are exquisitely sensitive to the dispositional status of the participants in the events as causal agents. The present studies aims to investigate these effects outside the domain of caused motion.

The Intentional Agency account makes two crucial predictions that differentiate it from the Michottian one. First, infants' earliest causal schemata should involve intentional agents as the causal agents in particular events and the causal dispositional status (as a typical intentional agent) of the participants in events should affect infants' causal representations of those events. Second, there is no reason infants' earliest causal schema should be restricted to motion events. Infants should be able to represent state change events as causal as early as they can represent motion events as causal. The present studies test both of these predictions.

There is a third research tradition in studies of causal representations in which the basic causal schema is one of representing which events make a difference to the occurrence of others. In this tradition, perhaps the dominant one in philosophical analyses of causation (Hall, 2004; Woodward, 2007), causal representations are closely related to a certain type of counterfactuals. Representing that the lightning's hitting the oak tree caused the forest fire is equivalent to representing "if the lightning had not struck the oak tree, the forest fire would not have happened." On this third account, the inputs to causal representations are conditional probabilities among events (Cheng, 1997; Pearl, 2000; Spirtes, Glymour, & Scheines, 1993). As mentioned above, we endorse this account of adult causal representations. It is possible that infants' causal representations might also be captured by this analysis. The origin of our capacity for causal representations may lie in domain general statistical processors that compute conditional dependencies between distinct events and draw causal conclusions from these computations (see Spirtes et al., 1993, Tenenbaum, Griffiths, & Kemp, 2006, for different views of the nature of these computations; see Gopnik et al, 2004, for a review of evidence that young children represent causality in this way). However, while there is recent literature on infants' representations of conditional probabilities (e.g., Sobel & Kirkham, 2006), and their use of such data in various learning contexts (e.g., Saffran, Aslin, & Newport, 1996), it has yet to be shown that the infants use such data to compute causal representations.

This third account, which we call "the conditional dependency account," makes no commitment as to which are the first causal representations infants will form; it will depend upon the statistical evidence they receive. Analysis of covariation data could lead either to causal analyses of Michottian motion events or to causal analyses of human intentional action. In the current paper, we ask whether the same patterns of statistical dependence lead to different causal analyses in different contexts, and if not, question the nature and source of additional constraints that explain the pattern of data we see. We compare infants' causal representations of Michottian launching events, for which they have presumably had massive statistical evidence in their first 6 months of life, with their causal representations of novel state change events, for which the main evidence for covariation between events derives from the experiment itself.

The current experiments seek to expand the domain of events infants may represent causally from motion events to physical state changes. We adapt Ball's (1973) causal inference method to the study of events in which a potential situational agent passes behind a screen, after which a partially hidden box changes color and plays music, or events in which the box breaks into several pieces. During familiarization, infants do not witness the interaction between the potential agent and the box. We seek the same sorts of evidence for causal representations of these state changes as has been offered for causal representations of motion events. Specifically, we test whether infants are sensitive to the effect happening upon contact with the agent, such that, when they are shown the full events, their attention is drawn if the potential situational agent fails to contact the object and the effect happens (Experiments 1–3) and if the potential situational agent contacts the object and the effect does not happen (Experiment 4).

We organize the studies in terms of contrasting the predictions of the Michottian account of the earliest causal schemata with the Intentional Agency account. We ask whether, as the Michottian account suggests, only motion events are represented causally. If, instead, we find evidence that infants also form causal representations of state changes, we ask whether, as the Intentional Agency account suggests, the situational agent must be an intentional agent. We then consider, in the general discussion, the implications of what we have learned about infants' early causal schemata for the origin of the human capacity to understand the world in terms of causality.

Experiment 1 – Launching

The goal of Experiment 1 is to replicate the original Ball (1973) finding that infants infer contact in ambiguous motion events in which the motion of object follows the approach of another, and in which the interaction between the two is not witnessed. Because 8-month-olds are the youngest infants who have demonstrated this phenomenon in Ball's paradigm (Kosugi & Fujita, 1998; Woodward et. al., 1993), the participants in this study, and those who will participate in the very similar state change events in Experiment 2–5, are 8-month-olds.

In Experiment 1 we habituated infants to an ambiguous motion event and then compared their looking times to two unoccluded test events – an event in which the potential agent contacts the box and the box moves and an event in which the potential agent stops short of the box and the box moves. Following Ball (1973) and others, we predicted that infants should have increased looking times to the event in which the potential agent stops short of the box. Previous studies suggest that the habituation event is necessary for observing these effects. Infants do not have baseline preferences for gap events over contact events (Oakes & Cohen, 1990). Kotovsky & Baillargeon (2000) suggested that when infants are shown the gap and contact test events in the absence of habituation, they do not look longer at the gap event because they interpret the event in which A approaches B, followed by the motion of B with no contact between the two, as evidence that object B is self-propelled (see also Schlottman and Surian, 1999; Schlottman, Surian & Ray, 2009). Thus, experience with the habituation events sets up the causal interpretation consistent with Michottian launching.

Method

Participants were 20 8-month-old infants (mean = 8 months 12 days, range = 7 months 27 days to 9 months 2 days; 11 female). An additional 3 participants were eliminated for crying that prevented completing the study (n = 3).

The experiment involved 3 phases: a habituation phase, a familiarization phase, and a test phase. Infants were seated on their parents' lap facing a stage (36 in × 20 in). The events are diagrammed in Figure 1. Habituation events began with a stationary red box (5.5 in × 6 in), partially occluded by a black free-standing screen (10.5 in. × 7 in.). A train (6.5 in × 5 in.) entered the stage, stopped, and the experimenter said "Look, [baby's name], look!" (Fig. 1a). The train then moved towards the box (3 s), moved entirely behind the screen, after which the box moved away from the screen (2 s) to the end of the stage (Fig. 1b). The nature of the interaction between the train and the box was occluded from the infants' view. A hidden camera recorded infants' looking time towards the stage. A coder recorded the amount of looking from the start of the box's launching and ended a trial when the infant looked way for 2 consecutive seconds, as computed by the Xhab coding software program (Pinto, 1995). The coder was blind to the trial type during the test trials. The habituation phase ended when the sum of an infant's looking time on 3 consecutive trials decreased to half the sum of looking time on the first 3 trials, or when the infant reached a maximum of 12 trials.

Following the habituation phase, the screen was removed, and infants viewed a familiarization event of the stationary train and the stationary box in position from the beginning of a trial (Fig. 1c). This ensured that any dishabituation during the test phase was driven by a representation of the test events, rather than by the removal of the screen and/or first exposure to the entire stage. This event was presented for 10 s, independent of infant looking.

There were 2 types of test events (contact and gap), in alternation, for a total of 4 trials. At the start of each trial, the box was at rest and unoccluded. In the contact event, the train entered the stage, stopped, and the experimenter said "Look, [baby's name], look!" The train then moved towards the box, contacted the box (Fig. 1d), after which the box immediately began to move (Fig. 1e). The gap event was identical to contact event, except that the train stopped short (2 in.) of the box (Fig. 1f), at which time the box immediately began to move (Fig. 1g). As during the habituation trials, the coder recorded the amount of looking time to the stage after the start of the box's launching. This ensured that the trial did not end prior to the relevant spatial relations between the train and the box (gap vs. contact) was presented to the infant. A test trial ended when the infant looked away for more than 2 consecutive seconds. The order of test trials (gap vs. contact) was counterbalanced between subjects. Parents were instructed to close their eyes during the test events, to ensure that they did not inadvertently influence infant looking time.

One third of the participants' data were double-coded by an additional coder, either live or after the initial data collection. Interobserver agreement on those infants' looking time, calculated by sampling agreement between the two coders at 1/10 second intervals across each trial, was high, .92. The looking times from the first coder were used in all analyses. To ensure that each participant received similar presentations across condition, we reviewed the videotaped experimental sessions for experimenter bias. In particular, an additional coder, unaware of the infant's experimental condition or of trial type, coded the experimenter's speaking of "Look, [baby's name], look," for how engaging the phrase sounded in 25% of the infants in each of the experiments reported in this paper. We found no effects of the independent variables across all experiments in this paper in animation or engagingness of the experimenter's utterances.

Results and Discussion

In all analyses of all experiments reported here, p values are 2-tailed unless otherwise specified. An analysis of the average looking time to habituation trials revealed that infants significantly decreased looking from the first three habituation trials (6.5 s) to the last three habituation trials (4.4 s; $t(19) = 2.49$, $p < .05$; see Figure 2). Ten of the infants reached criterion for habituation (mean = 9 trials). The remaining 10 infants were presented the maximum of 12 habituation trials. A preliminary analysis established that habituaters and non-habituaters did not differ from each other on the test trials, so further analyses were collapsed over habituation status.

Infants looked significantly longer at the gap test event (6.0 s) than at the contact test event (4.5 s; $t(19) = 2.42$, $p < .05$; see Figure 2). Fifteen out of 20 infants showed this pattern of looking (Wilcoxin $Z = 2.32$, $p < .05$). Furthermore, infants significantly recovered attention from habituation to the gap test event (mean difference from the last 3 habituation trials to the first gap test event = 2 s; $t(19) = 2.15$, $p < .05$), but generalized their habituation to the contact test event (mean difference = .8 s, *n.s.*).

Experiment 1 replicates Ball's (1973) result under similar conditions and with the same age participants to be tested in the remaining studies. Although they did not witness the interaction between the train and the box during the habituation phase, the infants' attention was drawn more to the unoccluded test events in which the train stopped short of the box and the box subsequently went into motion than to test events in which the motion of the box immediately followed contact from the train. While this result by itself does not establish that infants interpret these events causally, it is one part of the full pattern reviewed above. Here, infants' attention is drawn if the effect occurs, but contact between the situational agent and the patient did not. Infants also recover interest if the contact between the situational agent and patient occurs, but the effect does not (Kotovsky and Baillargeon, 2000). Finally, infants are sensitive to the causal dispositional status of the interacting entities (Saxe & Carey, 2006). Altogether, these results suggest that infants interpreted the interaction between events during familiarization in terms of physical contact causality. The remaining experiments explore whether this full pattern of results is also observed in infants' representations of state changes not involving motion in the patient object.

Experiment 2 – State Changes

Experiment 2 begins to investigate Michotte's prediction that causal representations of motion events are developmentally primary. If so, 8-month-old infants may not represent physical state change events as causal, and therefore may not be affected by the gap-contact contrast if the effect on the patient is a state change rather than motion. Infants were familiarized to the same train entering behind the barrier, with the box partially visible on the other side. After the train was completely occluded, the box underwent a state change. The question is whether during fully visible test trials infants' attention is drawn more to gap events in which the effect occurs in the absence of contact, compared to contact events. We tested two types of state changes: color change/music (the front panel of the box changed color and the box began to play music) and breaking (the box broke into pieces).

Method

Forty 8-month-old infants (mean = 8 months 14 days, range = 7 months 23 days to 9 months 5 days; 17 female) were recruited. Each was assigned to one of the two state change conditions. An additional 5 participants were eliminated for crying that prevented completion of the study.

The procedure was identical to Experiment 1, with the exception of the effects on the box (Figure 3). In the color change/music condition, the train moved towards a partially occluded box with a white translucent front panel (8 in. × 3 in.), passed behind the screen, after which the front panel changed color (from white to red) and played a short musical tune. In the breaking box condition, the train moved towards the partially occluded red box (5.5 in. by 6 in.), passed behind the screen, after which the box broke into a pile of 5 pieces. To ensure that infants viewed the box on the stage as solid, infants in the breaking box condition played with a solid replica of it prior to entering the testing room.

As in Experiment 1, familiarization trials were followed by an intertrial, in which infants viewed the train and the box at rest on the stage for 10 s, and then by fully visible test trials in which the train approached the box, making contact or stopping short, upon which the state change occurred.

Results and Discussion

A preliminary analysis revealed no significant differences between the two different state change conditions (color change/music and breaking) in looking to the habituation events (first three trials: 12.2 s vs. 12.9 s, respectively; last three trials: 5.6 s vs. 7.3 s) or to the test events (contact: 7.2 s vs. 7.7 s; gap: 5.9 s vs. 7.9 s; all *p*s > *n.s.*). Therefore, the data were collapsed across state change type for all subsequent analysis.

The majority of infants (26) habituated to the occluded state change event (mean = 9 trials). Fourteen infants viewed the maximum of 12 habituation trials without habituating. Across all infants, the average looking time decreased from the first three habituation trials (12.6 s) to the last three habituation trials (6.5 s; $t(39) = 5.92$, $p < .01$; see Figure 4). There were no main effect of habituation status on looking times during the test events, $F(1,38) = .022$, *n.s.*, nor did habituation status significantly interact with test trial type, $F(1,38) = .168$, *n.s.*. Therefore, the data from habituaters and non-habituaters were collapsed for subsequent analysis.

Infants did not discriminate the test trial events. Unlike in Experiment 1, they looked equally long at the gap test event (6.9 s) and the contact test event (7.5 s; $t(39) = .9$, *n.s*.; see Figure 4). Nonparametric analysis confirmed no significant difference in looking times to the test events, with only 16 of 40 infants looking longer at gap test events (Wilcoxin $Z = 1.28$, $p = .2$). Infants also did not significantly recover looking time from the last 3 habituation events to either the gap test events (mean difference = .5 s; $t(39) = .626$, *n.s.*) or to the contact test events (mean difference = .9 s; $t(39) = 1.865$, *n.s.*). Finally, we confirmed that these null results were not due to the non-habituaters. The 26 infants who reached habituation criterion also failed to look longer at the gap test events (6.8 s) than at the contact test events (7.2 s; $t(25) = .57$, *n.s.*).

Next, we compared infants' representations of launching events in Experiment 1 to those of the state change events in Experiment 2. We first examined looking times during the habituation trials. An ANOVA examined the effects of event type (launching vs. state changes) and trial block (first 3 trials vs. last 3 trials) on looking time to habituation events. There was a significant main effect of trial block, $F(1, 58) = 26.78$, $p < .001$. Infants decreased looking to both the occluded launching and state change events during the habituation period. There was also a significant main effect of event type, $F(1, 58) = 21.59$, $p < .001$. Infants looked longer at the state change habituation events (9.5 s) than at the launching habituation events (5.5 s). This difference was expected, given that both of the state changes were much more novel than the simple launching event. Finally, there was a significant interaction between event type and trial block ($F(1, 58) = 6.45$, $p < .02$). This interaction reflected a greater decrease between the first 3 and last 3 habituation trials during the state change events (6.1 s decrease) than in the motion events (2 s decrease). The greater percentage of infants in the state change conditions reaching habituation criterion (65% vs. 50% in the launching condition) and their greater overall decrease in looking times during habituation (6.1 s vs. 2.1 s in the launching condition) suggest that their failure to differentiate the test events was not due to a failure of encoding the events during habituation.

A final ANOVA examined the effects of event type (launching vs. state changes) and trial type (gap vs. contact) on looking times during test events (compare test events in Figures 2 and 4). There was a significant main effect of event type, $F(1, 58) = 7.94$, $p < .01$, but no significant main effect of trial type. Infants looked longer at the state change events (7.2 s) than at the launching events (5.2 s), again reflecting the greater intrinsic interest of the state change events. Importantly, the two variables interacted, $F(1, 58) = 4.04$, $p < .05$. Infants differentiated the gap and contact test events in the launching condition ($t(19) = 2.42$, $p < .05$), but failed to do so in the state change conditions ($t(39) = .9$, *n.s.*), and this difference in pattern was statistically reliable. This interaction also reflects the fact that it was only looking times to contact events that distinguished the launching and the stage change test trials ($t(58) = 3.829$, $p < .05$) - infants looked equally long at the gap events in both conditions ($t(58) = .987$, *n.s.*). Thus, the interaction between event type and trial type reflects the fact that only infants in the launching condition generalized habituation to the contact test events, as if these events were consistent with the representations they had established during habituation.

Experiments 1 and 2 provide support for the hypothesis that representations of physical contact causality in motion events constitute the earliest developing causal schema. Infants represented the motion of the train as the source of the box's subsequent motion, as indicated by their sensitivity to the spatial relations between the train and the box – a result that corroborates similar findings from three other laboratories (Ball, 1973; Kosugi & Fujita, 2002; Woodward et al., 1993). Infants were not, however, sensitive to the spatial relations between the train and the box when the box underwent a physical state change. This is so even though during the habituation trials of Experiment 2, the conditional probability of the state changes, given the approach of the train toward the box behind the barrier, was identical to the conditional probability of box motion, given the approach of the train, in Experiment 1 (namely, $p = 1$). This suggests that infants' sensitivity to contact in the launching events was supported by specific schemata brought to the task by 8-month-old infants. That is, these data show that by 8 months of age, infants' sensitivity to the spatial relations between two objects in an occluded event is not determined solely by processes that compute causality from conditional probabilities between the variables of those events alone.

The data from Experiment 2 suggest that infants did not consider the motion of the train as the cause of the state changes. An alternative interpretation of the findings is that infants represented the box's subsequent state change as caused by the train without contact. Whereas contact may be a constraint on infants' representations of launching events, infants may accept action-at-a-distance in state change events. Either interpretation would predict equivalent looking at the contact and gap test events in Experiment 2. Experiment 3 distinguishes between these alternatives, as well as testing a critical prediction of the Intentional Agency hypothesis about initial causal schemata – that infants' causal representations should be primarily influenced not by the type of effect in the event (launching vs. state change), but instead by the dispositional status of the agent in the event (intentional agent vs. inanimate entity).

As described above, recent evidence suggests that the causal dispositional status of the agents and patients in motion events influences causal interpretations even at the earliest ages at which causal representations are observed at all (see Saxe & Carey, 2006, for a review). Since representations of causal dispositional status lie outside of the restricted spatiotemporal parameters that determine Michottian causal perception, such findings implicate a potential schema for causal representations aside from a Michottian launching schema. These studies provide clear evidence that infants' representations of the dispositional features of the individual influence their causal representations of motion events. Here we seek an even stronger relation between causal attribution and representations of the dispositional features of a potential situational agent. We explore whether if the entity seen to approach the box behind the barrier is a dispositionally causal agent, the infant will interpret it as the causal source of the state change, inferring contact where they failed to in Experiment 2. Specifically, we asked whether infants would successfully represent a prototypical intentional agent (a hand) engaging in an intentional action (a deliberate approach) – a prototypical agent – as the cause of the state change events, and therefore recover interest to the gap test trials. The most straightforward interpretation of this result, if obtained, is 1) that infants are sensitive to the spatial relations between a potential agent and a potential patient in physical state change events, and 2) that they failed to interpret the train's motion as causing the state change in Experiment 2 because they did not represent it as a dispositionally causal agent.

Experiment 3 – Hand as a Potential Agent

Method

Participants were forty 8-month-old infants (mean age = 8 months 8 days, range = 7 months 27 days to 8 months 30 days; 20 female). Infants were assigned to one of the two state change conditions (color change/music or breaking). An additional 4 participants were eliminated for fussiness (n = 4). Infants were given a small toy for their participation, and parents were reimbursed travel costs.

The procedure was identical to Experiment 2, with the exception that a hand, rather than a toy train, was the potential agent in the occluded state change events (Figure 5).

Results and Discussion

A preliminary analysis revealed no significant differences between the two state change conditions (color change/music and breaking) in looking time to the habituation (first three trials: 11.3 s vs. 11.6 s, respectively; last three trials: 6.0 s vs. 6.2 s) or test events (contact: 6.8 s vs. 5.3 s; gap: 8.9 s vs. 6.8 s; all *p*s > .05). Therefore, the data were collapsed across state change conditions for all subsequent analysis.

Thirty of the infants reached criterion for habituation to the occluded state change events (mean = 9 trials). The remaining 10 infants were presented with the maximum of 12 trials. An analysis of average looking time to the habituation events revealed a significant decrease from the first three trials (11.5 s) to the last three trials (6.1 s), $t(39) = 10.3$, $p < .01$ (Figure 6). A further analysis established that habituaters and non-habituaters did not differ in their looking times to the test events. There were no main effect of habituation status on looking times during the test events, $F(1,38) = .03$, *n.s.*, nor did habituation status significantly interact with test trial type, $F(1,38) = .568$, *n.s.*. Therefore, further analyses were collapsed across habituation status.

Infants looked significantly longer at the gap test events (7.9 s) than at the contact test events (6.1 s), $t(39) = 2.8$, $p < .01$ (see Figure 6). Twenty-seven of the 40 infants showed this pattern of looking (Wilcoxin $Z = 2.58$, $p = .01$). Finally, there was a significant difference between infants' average looking time to the last 3 habituation trials (6.1 s) and to the gap test events (7.9 s), $t(39) = 2.86$, $p < .01$, but not the contact test events (6.1 s), $t(39) = .02$, *n.s.* Infants recovered attention to the gap test events, but generalized habituation to the contact test events.

Infants were sensitive to the spatial relations between the hand and the box undergoing the state change equally for the color change/music events and the breaking box events. Thus, this experiment provides no support for Michotte's hypothesis that physical state changes involving motion (the collapsing box) are assimilated to events in which the motion of the situational agent is transferred to the situational patient, and thus represented causally more easily than are other state changes.

Two final analyses compared infants' representations of the occluded state change events in Experiment 3 to those of Experiment 2. First, to assess any differences in looking time during the occluded state changes (habituation event), we conducted an ANOVA on the effects of potential agent (hand vs. train) and trial block (first 3 trials vs. last 3 trials) on infants' looking time to the habituation events. There was a main effect of trial block, $F(1, 78) = 98.89$, $p < .001$, but there was no significant main effect of potential agent, $F(1, 78) = 1.12$, *n.s*, and no significant interaction between potential agent and trial block, $F(1, 78) = .36$, *n.s.* Infants were equally interested in the occluded state change event, and decreased looking over familiarization trials equally, when either the hand or the train was the potential agent. Thus, any further differences in the patterns of looking times to test events as a function of agent type cannot be attributed to differences in looking times to the habituation events or to greater interest in the hand than in the train.

Second, an ANOVA examined the effects of potential agent (hand vs. train) and trial type (gap vs. contact) on infants' looking time to state change test events (see test event looking time in Figure 4 and 6). There was no significant main effect of potential agent, $F(1, 78) = .094$, *n.s.*, or of trial type, $F(1, 78) = 1.81$, *n.s*. There was a significant interaction between potential agent and trial type, $F(1, 78) = 6.787$, $p < .05$. Infants discriminated the gap and contact test trials when the hand was the potential agent ($t(39) = 2.8$, $p < .01$), but failed to do so when the train was the potential agent ($t(39) = .9$, *n.s.*). This interaction also reflects the fact that looking at the contact test trials was significantly shorter in the hand condition than the train condition ($t(78) = 2.1$, $p < .05$), whereas the infants in the two conditions did not differ in their interest to the gap events ($t(78) = 1.2$, *n.s.*). That is, the interaction reflects the fact that infants generalized habituation to the contact events only in the hand condition, as if these events were consistent with the representations they had formed in the habituation phase.

Although infants were *not* sensitive to differences in the contact relation between a *train* and a box that underwent a state change (Experiment 2), they *were* sensitive to contact between a *hand* and a box undergoing the very same state changes (Experiment 3). Thus, infants' sensitivity to the contact relations depends both on the type of state change (launching vs. non-motion state changes) as well as the type of agent (prototypically causal or inert). That sensitivity to contact depends on other causally relevant variables is evidence that it reflects causal attribution. That is, we take this as evidence that infants' representations of the dispositional features of the agent influenced their causal representations. Unlike previous experiments, which have demonstrated the effects of representations of the dispositional features of agents on how a causal motion event is construed, this experiment suggests that infants' representations of the dispositional features of the agent influenced *whether or not* the event was represented as causal.

One concern in comparing the results of Experiments 2 and 3 is that infants may have attended more to the hand in Experiment 3 than to the train in Experiment 2. If so, then infants in Experiment 3 may have had more of an opportunity to detect the correlation between the potential agent's motion and the box's effect, leading to the differences between experiments on looking to the test events. One reason to doubt this explanation is that all infants attended to the agent after the onset of the agent's motion. Thus, all infants received the equivalent conditional probability evidence that the box's effect occurred following the motion of the agent. Second, the ANOVA on total looking time during habituation revealed no differences between the train and hand events. Finally, to explore the possibility in one more way, we examined interest to the train or hand when stationary, at the beginning of each habituation trial. We randomly selected 1/3 of the infants from each of the conditions (total $n = 14$ per experiment) in Experiments 2 and 3 and coded the percentage of time infants looked at the potential agent at the start of the habituation trial prior to the agent's motion. The percentage of time that infants' looked at the agent prior to the onset of the agent's motion thus served as a measure of the saliency of the agent. To assess any differences in attending to the agent, we conducted an ANOVA on the effects of the type of agent (hand vs. train) and trial block (first three habituation trials vs. last three habituation trials) on the average of infants' percentage of time looking to the agent. There was a main effect of trial block, $F(1, 26) = 19.51$, $p < .001$. Infants increased looking to the stationary agent from the first three habituation trials (64.4 %) to the last three habituation trials (83.7 %), presumably because they anticipated the subsequent motion they had come to expect. Importantly, however, there was no main effect of agent, $F(1, 26) = 1.52$, $p =$ *n.s.*, and no interaction between agent and habituation trial block, $F(1, 26) = .18$, $p =$ *n.s*. Thus, infants found the two agents equally salient, attended equally to the different agents across the habituation phase, and had equivalent opportunity to encode the conditional probability information present in the habituation events.

These results undermine two crucial predictions of Michotte's account of the origin of causal reasoning. Infants very close in age (8-month-olds) to those of the earliest ages in which there is good evidence for causal representations Michottian motion events (6 months) form causal representations of state changes. If causal perception of motion events were the sole source of causal cognition, it is difficult to imagine what might have led to a generalization of this schema to state changes in so short a time. Also undermining Michotte's theory, factors beyond the spatiotemporal features of the events influence causal attribution. Rather, the Intentional Agency theory's prediction that the dispositional features of the agent, and not only the nature of the effect, play a critical role in infants' causal representations, receives support.

As in Experiments 1 and 2, the conditional probability of the state change, given the approach of the hand, was identical to the conditional probability given the approach of the train (p = 1). Furthermore, infants had experienced this conditional probability equally in the hand and train state change events. Again, factors beyond this statistical information influences causal attribution: the nature of the effect (compare Experiments 1 and 2) and the nature of the agent (compare Experiments 2 and 3).

The results of Experiment 3, however, are still open to an alternative interpretation to that we have assumed. It is possible that infants' sensitivity to contact in the occluded state change events did not rely on a causal representation of the event. Rather, perhaps infants simply are sensitive to contact changes in any event involving a human hand deliberately approaching an inanimate entity. That is, they may have interpreted the hand as engaging in a goal-directed reach (as in Woodward, 1998) and expected the hand to contact its goal.

Alternatively, if infants represented the occluded state change events involving hands as causal in Experiment 3, then infants should also be sensitive to the spatial relations between the hand and the box when the effect does not occur. Infants should not only look longer when the box *breaks* and the hand *fails* to make contact with it (Experiment 3), they should also look longer when the box *does not break* and the hand *does* contact it. Experiment 4 tested this prediction.

Experiment 4

Method

Participants were twenty 8.5-month-old infants (mean = 8 months 13 days, range = 7 months 23 days to 9 months 1 day; 10 female) were recruited for Experiment 4. An additional 4 participants were eliminated for fussiness (n = 3) or parental interference (n = 1).

We used only the breaking box condition in Experiment 4. The habituation and familiarization phases were identical to Experiment 3, but the following change was made to the test phase (Figure 7). Rather than breaking during the test phase, the box remained solid throughout the gap and contact test events. Therefore, during habituation trials, infants viewed the occluded breaking box event in which the hand approached the box, after which the box subsequently broke apart. Following the familiarization phase, the hand either contacted or stopped short of the box, which did not break.

Results and Discussion

Thirteen of the 20 infants habituated to the occluded breaking box event (mean = 9 trials). The remaining 7 infants viewed the maximum of 12 habituation trials. An analysis of all infants' looking time to the habituation events revealed that infants significantly decreased looking from the first 3 trials (11.1 s) to the last 3 trials (6.7 s), $t(19) = 3.68$, $p < .01$ (Figure 8). There were no main effects of or interactions involving habituation status on looking times during the test events, so the data were collapsed across habituation status for all subsequent analysis.

Infants showed the opposite pattern of looking in Experiment 4 to that revealed in Experiment 3. They again discriminated the test events, but looked longer at the *contact* test events (7.9 s) than the *gap* test events (5.9 s), $t(19) = 2.46$, $p < .05$. Nonparametric analysis revealed that 13 infants showed this pattern of looking, Wilcoxin $Z = 2.17$, $p < .05$. Finally, infants recovered attention from habituation to the contact test event (mean difference from the last 3 habituation trials to the first contact event = 3.4 s; $t(19) = 2.25$, $p < .05$), but generalized their habituation to the gap test event (mean difference from the last 3 habituation trials to the first gap event = .72 s; $t(19) = .73$, *n.s.*).

A final set of analyses compared infants' looking times to the breaking box events in Experiment 3 and Experiment 4. First, we conducted an ANOVA examining the effects of trial block (first 3 vs. last 3) and experiment (breaking – Experiment 3 vs. no breaking – Experiment 4) on looking time to the habituation events. There was a significant main effect of trial block, $F(1, 38) = 48.76$, $p < .001$, but no main effect of experiment or any interaction between these two variables, suggesting that infants had equivalent decreases in looking time during the habituation period across experiments. This is to be expected, of course, since the habituation events were absolutely identical in the two studies.

Second, an ANOVA examined the effects of experiment (breaking - Experiment 3 vs. no breaking – Experiment 4) and trial type (gap vs. contact) on looking times to the test events (see test event looking time in Figure 6 and 8). There was no significant main effect of trial type, $F(1, 38) = .16$, *n.s.*, nor of experiment, $F(1, 38) = 1.14$, *n.s.* There was a significant interaction, however, between trial type and experiment, $F(1, 38) = 9.52$, $p < .01$. Infants looked longer at gap test events when the box broke during Experiment 3, but looked longer at the contact test events when the box did not break during Experiment 4.

The results from Experiment 4 support our interpretation that infants represented a causal interaction between the hand and the box in the occluded state change events of Experiment 3. Infants looking time was not only sensitive to the spatial relations between the hand and the box during the occluded state change event, but this sensitivity depended on the presence (Experiment 3) or absence (Experiment 4) of the effect of the box. Since the habituation events in Experiment 3 and Experiment 4 were identical, infants in the two studies should have formed the same initial representations of the occluded state change event. We interpret this finding as further evidence that infants represented the habituation event as causal. Infants interpreted the hand as causing the state change and were thus sensitive to changes in contact between the hand and the box. Thus, their attention was drawn in the fully visible test trials when contact occurred and the state change did not (Experiment 4) or when contact did not occur and the state change did (Experiment 3).

Experiment 4 also rules out alternative interpretations of the findings that infants' attention was drawn to the gap event, independent of a causal representation, in Experiment 3. Infants did not merely encode the hand as *approaching* the box, or *reaching* for the box, expecting that hands typically contact entities they approach or that are their goals. If this had been the case, infants should have looked longer at the gap events in Experiment 4 as well as in Experiment 3.

Experiments 1–4 shed light on the nature of infants' initial schema for representing causal events. First, these results provide evidence against the hypothesis that conditional probabilities among the components of the witnessed events alone are the sole input to infants' causal representations. During the habituation phase of Experiments 1–4, the probability that the change in the box (launching, color/music, breaking) would occur, conditional on the approach of the potential situational agent behind the barrier was the same (p = 1). Moreover, infants had more evidence regarding these probabilities in the state change experiments (Experiments 2–4) than the launching experiment (Experiment 1) because they observed more trials during habituation in these experiments. Yet, they made causal interpretations of these events only in Experiment 1 (train causes motion of box) and in Experiments 3 and 4 (hand causes state change). That they did not do so in Experiment 2 (train causes state change) shows that the conditional probabilities they experienced during habituation were not the sole input into their causal representations. They must already represent specific causal schema, specific sensitivities about causal relations among events, that constrain their interpretations.

One of these schemata is likely to be the schema of Michottian launching, since infants were able to represent the causal relation between the train and the box in launching events of Experiment, and because the evidence that infants represent launching as causal even a few months earlier is massive, as reviewed in the Introduction. But how should we think about the schema that constrains their interpretation of the state change events? How abstract is it? Given the failure in Experiment 2, in which infants' looking time was not sensitive to changes in contact between the toy train and the box's physical state change, the schema does not extend to all moving objects as potential situational agents. Furthermore, it is unlikely that children have specific schemata concerning the exact state changes this box underwent, since these were novel. However, it is possible they might well have a schema that is restricted to moving hands as potential situational agents in state changes of inert objects. Alternatively, it may apply to any dispositionally intentional agent, however novel - infants may represent intentional agents as capable of causing state changes. We explore these alternatives in Experiment 5.

Experiment 5

Experiment 5 explores whether infants would use features of a potential situational agent – self-propelled motion and the presence of eyes – to represent it as a dispositional causal agent and thus represent a causal relationship between the potential agent and the breaking box.

Previous research has shown that infants take the presence of eyes as a cue to intentional agency (Johnson, Slaughter and Carey, 1998) and that self-propelled motion is likely to be a good cue to dispositional causal agency (Kotovsky & Baillargeon, 2000; Luo et al., 2009). Saxe et al. (2007) showed that both of these cues together are sufficient to lead 7-month-old infants to accept a novel entity as a causal agent of the motion of an inert object in an event where they had not witnessed the causal interaction between the agent and the patient. In Experiment 5, as in Saxe et al. (2007), we used both features in order to maximize the likelihood that infants would accept a novel entity as a dispositional causal agent.

Infants were familiarized with a novel entity with a face that displayed self-propelled motion. We then presented infants with the occluded breaking box event from Experiment 3, but replaced the human hand with the novel entity as the potential agent. If the schema supporting causal attribution in Experiments 3 and 4 is more abstract than merely "hands may cause state changes of entities upon contact," and the cues to dispositional agency we have included in this study are sufficient to lead the child to accept the novel entity as the cause of the box's breaking, then infants should show the same pattern of results as in Experiment 3 - longer looking to the gap test events.

Method

Participants were twenty 8.5-month-old infants (mean = 8 months 17 days, range = 8 months 3 days to 8 months 30 days; 11 female) were recruited for Experiment 5. An additional 3 participants were eliminated for fussiness (n = 3).

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The method was identical to that of Experiment 3, with the following exceptions. First, we replaced the human hand with a novel self-propelled object that had a face. The novel self-propelled object was approximately the same dimensions (6.5” × 3.5”) as the toy train presented in Experiments 1 and 2, and was composed of two Styrofoam balls covered with fabric of the same colors as the train. Second, prior to the habituation trials, we presented the infant with a 20-second familiarization trial, independent of infant looking, in which the infant saw the novel self-propelled object independently hop around the stage (Figure 9). Following this familiarization trial, the habituation trials, familiarization trial, and test trials proceeded identically to the procedure described in Experiment 3.

Results and Discussion

Twelve of the 20 infants habituated to the occluded breaking box event (mean = 9 trials) when the self-propelled novel entity was the potential agent. The remaining 8 infants viewed the maximum of 12 habituation trials. An analysis of all infants’ looking time to the habituation events revealed that infants significantly decreased looking from the first 3 trials (11.6 s) to the last 3 trials (6.2 s), $t(19) = 4.53$, $p < .001$ (Figure 10). There were no significant differences between habituaters and non-habituaters in looking to the test events, so the data were collapsed across habituation status for all subsequent analysis.

Infants looked significantly longer at the gap test events (9.8 s) than at the contact test events (6.1 s), $t(19) = 4.54$, $p < .01$. Thirteen of the 20 infants showed this pattern of looking (Wilcoxin $Z = 3.24$, $p < .01$). Finally, there was a significant difference between infants’ average looking time to the last 3 habituation trials (6.2 s) and to the gap test events (9.8 s), $t(19) = 3.7$, $p < .01$, but not to the contact test events (6.1 s), $t(19) = .09$, *n.s.* Infants recovered attention to the gap test events, but generalized habituation to the contact test events.

Thus, the pattern of results was the same as that observed when the potential agent was a hand, in spite of the vast perceptual differences between the novel agent and a hand. The novel agent disappeared entirely behind the screen before the state change occurred, as did the train, whereas the arm was still visible on the side opposite the box when the box collapsed or changed color and played music. Conversely, the pattern differed from that observed in Experiment 2, in spite of the fact that the novel agent was the same size and colors as the train. Three final analyses confirmed that the difference in results in the test trials between the train condition in Experiment 2 and the novel agent condition of Experiment 5 were statistically reliable, and were unlikely to derive from greater interest in the novel agent than in the train. First, an ANOVA examined the effects of potential agent (train vs. novel agent) and test trial type (gap vs. contact) on test trial looking times. There was no main effect of agent, $F(1, 58) = 1.1$, *n.s.* There was a main effect of trial type, $F(1, 58) = 8.2$, $p < .01$. Infants looked longer at the gap test trials (8.4 s) than at the contact test trials (6.8 s). There was also an interaction between trial type and agent, $F(1, 58) = 15.47$, $p < .01$. This interaction reflects the fact that infants discriminated the test events when the novel agent was the potential agent, $t(19) = 3.49$, $p < .01$, but did not do so when the train was the potential agent, $t(39) = .9$, *n.s*. The interaction also reflects the fact that infants looked at the gap test trials significantly longer in the novel agent condition (9.8 s) than in the train condition (6.9 s; $t(58) = 2.9$, $p < .05$), whereas infants displayed a trend to look longer at the contact events in the train condition (7.5 s) than in the novel agent condition (6.1 s; $t(58) = 1.7$, $p = .1$). Second, an ANOVA examined the effect of potential agent (train vs. novel agent) and trial block (first 3 trials, last 3 trials) on looking times during habituation. There was a main effect of trail block, $F(1, 58) = 44.47$ $p < .001$, but no main effect or interactions involving agent. Thus, infants appeared equally attentive to the train as to the novel agent. That the novel agent was no more salient than the train was put to further test in a final analysis of infants’ attention to these entities when they were stationary at the very beginning of each habituation trial. We randomly selected 1/3 of the participants in Exp. 5 (n

= 7) and coded the percentage of time infants spent looking at the stationary agent during this period. An ANOVA examined the effects of agent (novel toy in Experiment 5 vs. train in experiment 2 (n=14)) and trial block (first three habituation trials vs. last three habituation trials) on this measure. Infants' percentage looking to the agent increased from the first three habituation trials (65.7 %) to the last three habituation trials (80.1 %), as confirmed by a main effect of trial block, $F(1, 19) = 7.52$, $p < .05$. Importantly, however, there was no main effect of agent, $F(1, 19) = 1.4$, p = *n.s.*, and no interaction between the factors, $F(1, 19) = .01$, p = *n.s*. That looking times to the stationary agent increased during habituation equivalently in the two conditions suggests that infants in both conditions were equally anticipating that the train and the novel agent would begin to move behind the screen. There is no evidence that the novel agent was any more attention grabbing than was the train, or that the encoding of the habituation events was any more complete.

In Experiment 5, as in the hand conditions of Experiment 3, infants recovered interest from the last three habituation trials to the gap event, but not to the contact event, and during test trials they looked longer at the gap events than at the contact events. These data suggest that infants attributed the cause of the braking box to the novel entity in the occluded habituation events, and that during test they saw the contact events as consistent with this construal and the gap events (in which the effect happened with contact) as inconsistent with it. We take this as further evidence that infants are able to reason about the potential causes of occluded state changes, and that representations of an entity as the kind of thing that might be a causal agent influence the likelihood of a causal attribution.

The results from Experiments 3–5 suggest that by 8.5 months of age, infants represent a fairly abstract causal schema according to which certain classes of dispositional agents (entities capable of self generated motion; entities with faces, hands) are potentially capable of causing state changes through contact with the entity that undergoes a state change. The potential situational agent in Experiment 5 was novel, and so the infant could have no previous experience representing this agent causing state changes, unlike their experience with human hands causing state changes. The present experiments suggest that the relevant causal schema is abstract in a second sense as well. The state changes involved are also relatively novel and are very different from launching—the infant has vastly more experience with objects going into motion upon contact with other moving objects. Clearly, that vast experience is not necessary to support a causal interpretation of unseen events in which the motion of one entity reliably predicts a state change of another. This data suggests that so long as the entity observed going behind the screen immediately before the state change occurred was represented as capable of causal agency, infants apparently interpret it as causing the state change.

General Discussion

These studies are the first to explore whether young infants construe physical state changes not involving motion as causal, and if so, under which conditions they might do so. Eight-month-old infants were habituated to events in which a box's motion or its state change reliably followed the approach of a candidate cause of the motion or state change. Only part of the box was visible behind a screen, and infants did not witness the interaction between the potential agent and the box. To assess whether infants saw the change as caused by the potential agent, during test trials the infants witnessed the whole events. Within each experiment, on half of the test trials the candidate agent came in contact with the box and on the other half it did not. In most experiments the change occurred immediately upon contact or upon cessation of the candidate agent's motion; in one experiment (Experiment 4) the effect did not occur during the test trials.

The pattern of looking to contact and gap test trials was sensitive to three factors: the nature of the effect, the nature of the potential agent, and occurrence of the effect. With respect to the occurrence of the effect: in state changes following the approach of a dispositional intentional agent (hand or novel agent), infants' attention was drawn to fully visible *gap* events in which the effect *occurred* and to fully visible *contact* events when the effect *did not occur*. With respect to the nature of the effect: infants dishabituated to the gap event when the agent was a dispositionally inert train and the effect was motion (a launching event), but they failed to distinguish the gap and contact events with the same agent, when the effect was a state change (color change/sound or breaking apart). With respect to the nature of the agent: infants differentiated gap and contact events for state changes when the potential agent was a deliberately moving hand or a novel entity with eyes that had been shown to be capable of self generated motion, but not when the potential agent was a train.

Confirming previous studies, these data suggest that by 8-months of age, infants construe launching events causally and represent moving entities as situational causal agents irrespective of their dispositional status as animate intentional beings or as inert entities. Extending the previous literature, these data suggest that infants of this age can infer that a causal interaction has occurred in occluded physical state change events, and that the causal dispositional status of the potential situational agent (hand/self-propelled entity vs. train) influences the likelihood that the moving entity is taken as the cause of the state change.

These conclusions depend upon accepting that sensitivity to contact in these events is a marker of having interpreted the events causally. Several aspects of these data, along with other results in the literature, support this assumption. First, the presence or absence of contact partly underlies the categorical distinction between causal and non-causal events in causal perception studies (Cohen & Amsel, 1998; Leslie, 1982, 1984a; Oakes, 1994). It also predicts the attribution of causal roles to participants in launching events (Belanger & Desrochers, 2001). Furthermore, Leslie (1984b) found that infants are sensitive to contact relations only in adultdescribed causal entraining events. In this study, 6.5-month-old infants were habituated to either a non-causal reaching event or a causal pick-up event in which a hand picked up a doll. During test trials the infants viewed the same events with a change in contact relations between the hand and the doll. Only infants who were habituated to the causal pick-up event looked longer at a change in contact between the hand and the doll. Infants who were habituated to the reaching event did not recover attention to a change in contact.

The present Experiment 4 provided convergent evidence to Leslie's finding, extending it to infants' inferences about state changes. Infants were not simply sensitive to contact whenever a hand apparently approached an object in a deliberate, goal-directed manner. They dishabituated to the gap event in the test trials only when the state change occurred (Experiment 3). When the state change did not occur (Experiment 4) they dishabituated to a contact event. The most parsimonious interpretation of this set of findings is that infants interpreted the hand as causing the state change upon contact, and so their attention was drawn when the state change occurred in the absence of contact or when the state change failed to occur upon contact. This full pattern of results has also been observed in launching events: once infants have interpreted an interaction as launching, their attention is drawn if *a* does not make contact with *b* and yet *b* goes into motion and if *a* does make contact with *b* and *b* fails to go into motion (Kotovsky and Baillargeon, 2000; Luo et. al., 2009).

The present experiment provides convergent evidence to Leslie's study in yet another way – Leslie (1984b) also found that sensitivity to contact was a function of the dispositional agency of the potential situational agent. In our Experiments 2 and 3, infants interpreted the state changes causally when the moving entity was a hand but not a train, and in Leslie (1984b), infants apparently did not construe the pick-up event causally if the situational agent was a hand but not a block. That the causal dispositional status of the participants in events influences sensitivity to contact lends credence to the assumption that infants' sensitivity to contact reflects whether they have construed an event causally.

By "construing an event causally," we mean that infants represented the moving train or hand or novel agent as the source of the box's change. In the conditions in which infants did not look longer at the gap test event (i.e. – when the train was the potential agent in the state change test events), we do not necessarily conclude that infants did not represent the box's state change as self-initiated. Rather, we take the results from Experiment 2 to mean that infants did not represent the *train* as the situational causal agent. We might speculate that infants' elevated looking times during the test trials of the state change events with the train are indicative of their seeking a causal explanation of the box's state change.

A growing body of empirical data from infant studies constrains a theory of the origin of the human capacity for causal reasoning. The present studies confirm several generalizations from this literature and add three new results to it. First, by 8-months of age, infants' causal inferences are constrained by specific causal schemata. The inferences made in the current experiment were not solely dependent upon information about conditional probabilities that the effect would occur, given the approach of the potential situational agent, during the habituation trials, given that this conditional probability was the same across all experiments (namely, $p = 1$). Second, these schemata are quite abstract. They encompass unfamiliar state changes as well as often experienced launching events, and they encompass novel agents as well as highly familiar deliberate actions of hands. Third, the information relevant to these schemata is not limited to spatiotemporal properties of the events or to statistical relations among them; the dispositional status of the potential situational agent as an animate or intentional agent influences whether that potential agent is construed as the cause of a state change of another entity.

The data from this literature, including the present data, decisively rule out several historically important theories of the origin of causal representations. The first is Michotte's hypothesis that causal perception of motion events (launching, entraining, expulsion), based on spatiotemporal input alone, is the sole ontogenetic source of causal reasoning. Experiment 1 added another confirmation that young infants represent launching causally, and Experiment 2 found preliminary evidence for the Michottian prediction that causal representations of motion events precede causal representations of state changes. An important topic for further research is to explore whether younger infants, those of the earliest ages revealing causal interpretations of motion events, represent state changes causally when the situational agents are prototypical intentional agents. Still, Michotte's theory is undermined by two findings—the finding that state changes are interpreted causally by infants so young (8-month-olds), and the fact that information beyond spatiotemporal information influence infants' causal interpretations. The present experiments establish this latter fact in the case of 8-month-olds' causal interpretation of state changes. Saxe et al. (2007) established this fact in the case of expulsion events for infants as young as 7-month-olds; Leslie (1984b) for entraining evens at 6.5-month-olds, and Luo et al. (2009) for launching events for infants as young as 5 months old, which is the youngest age for which there is good evidence that launching events are represented causally at all.

Note, although these data undermine any theory in which Michottian causal perception is the sole ontogenetic source of human causal reasoning, they do not bear on whether causal perception of motion events may be innate or learned. It is certainly possible that innate mechanisms for creating causal representations of Michottian motion events exist, part of core cognition of objects and their interactions (Carey & Spelke, 1994; Carey, 2009), and that these are an aspect of a full account of the origin on causal cognition. It is also possible that a domain general statistical learning mechanism constructs these schemata over the first 8 months of life. Indeed, Cohen, Chaput, and Cashon (2002) have provided a connectionist model of how Michottian launching schema might be learned, although their model cannot account for the influence of causal dispositional status of the situational agents and patients on causal attribution. Also, the abstract schema that constrains causal interpretation of state-change events is unlikely to be learned by the same mechanism, simply because it applies to agents and state changes the child could have had no experience with.

Although the fact that infants' representations of interactions among events as causal is dependent upon the situational agents as intentional agents is loosely consistent with Piaget's account of the acquisition of causal concepts, his theory is also undermined by the recent data. First, infants represent Michottian events as causal as young as 6 months of age, even though these events do not involve an intentional agent. Second, because the state changes are novel, the causal schema could not have been generalized from the child's own experience.

How, then are we to interpret the close relations between representations of intentional agents and representations of causal agents? One possibility is that just as core cognition of objects may include innate representations of contact causality for motion events, core cognition of agents may include representations of the causal efficacy of some intentional actions, and this is one source of the human capacity for causal cognition (Carey, 2009). Alternatively, infants' vast experience with human agents over the first 8 months of age may facilitate the acquisition and generalization of this abstract causal schema. Clearly, the present findings, along with those of Leslie (1984b), Saxe et al. (2005, 2007), Luo et al. (2009) motivate further studies on the relations between representation of causal agency and representations of intentional agency. For example, Muentener (2009) found that the deliberateness of the arm action in Experiment 3 is necessary to the causal interpretation; if the arm flops down backward behind the screen, after which the box breaks, the infant does not make a causal interpretation, whereas if it arcs forward in a deliberate comparable motion, the infant does do so. It is not enough that the potential agent is an intentional agent; it must be represented as acting intentionally. Also, further research should examine which cues to intentional agency are sufficient for assigning causal responsibility to the potential agent in these studies.

In conclusion, the findings that the causal representations of very young infants are constrained by antecedently represented schema both of Michottian launching events and abstract schema of causal actions by intentional agents suggests that neither is the sole source of causal cognition. It is possible that the learning of both of these schemata is supported by a domain general mechanism that computes causality from patterns of statistical dependence. It is also possible that causal notions are part of two distinct domains of core cognition—object representations (contact causality of motion events) and agent representations (causally effective intentional action)—and that these representations are integrated very early in development.

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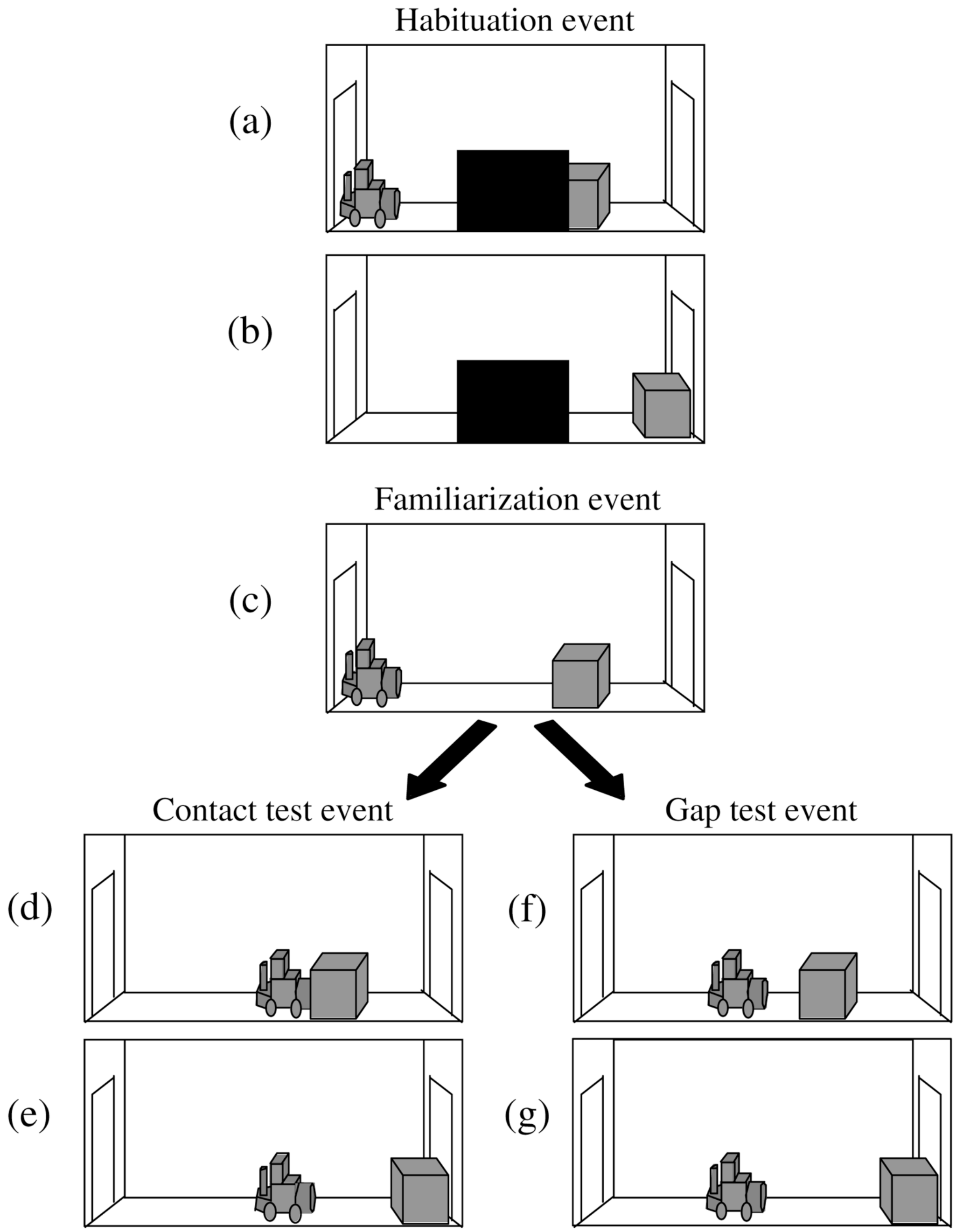

Figure 1.
Schematic depiction of the procedure for the launching condition in Experiment 1.

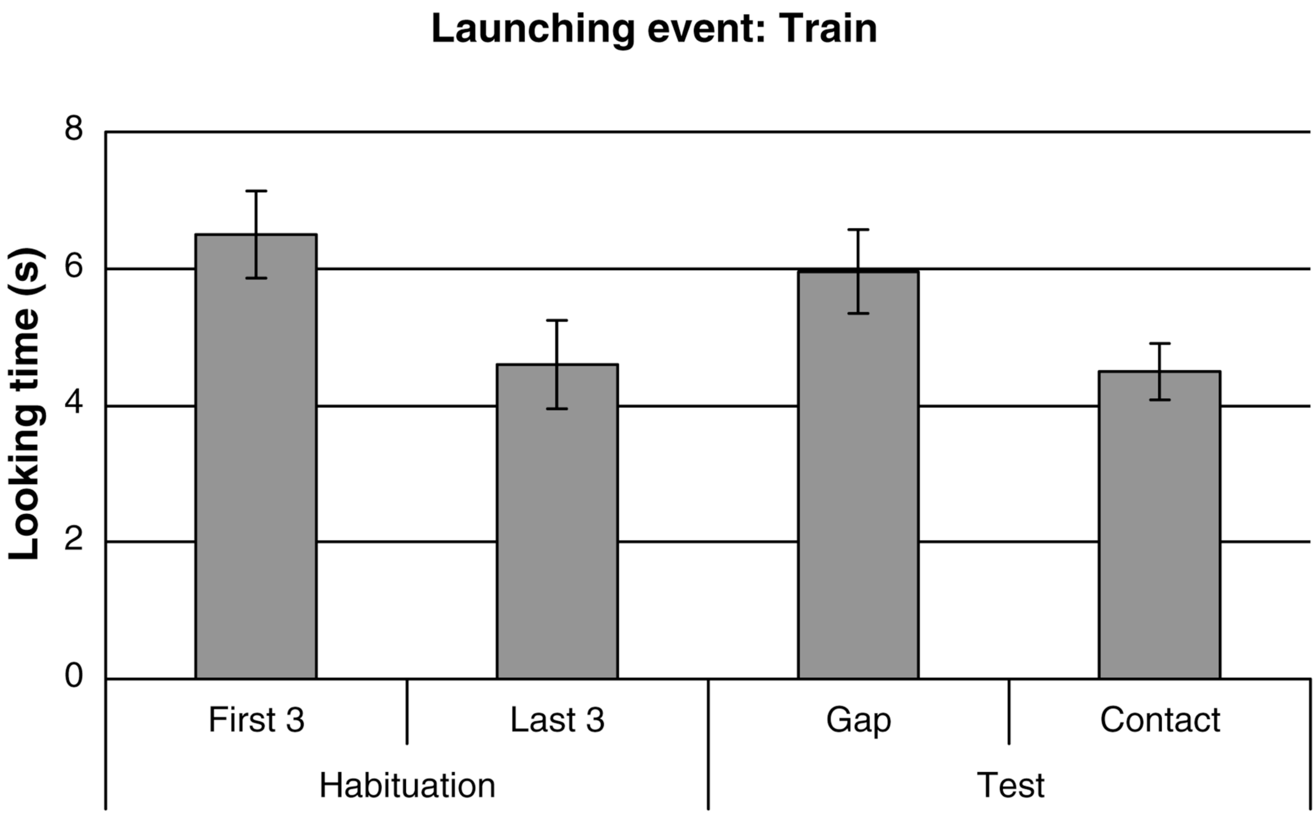

Figure 2.
Mean looking time (+ 1 *SE*) to the habituation and test trials in the launching condition (Experiment 1).

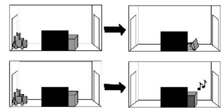

Figure 3.
Schematic depiction of the habituation trials in Experiment 2; a) breaking box, b) color change/ music.

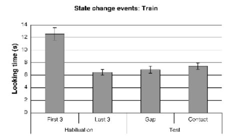

Figure 4.
Mean looking time (+ 1 *SE*) to the habituation and test trials in the state change events (collapsed across the color change/music and breaking conditions) from Experiment 2.

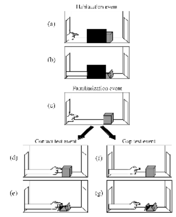

Figure 5.
Schematic depiction of the procedure for Experiment 3. The procedure was identical to Experiment 1, except that a human hand was the potential agent.

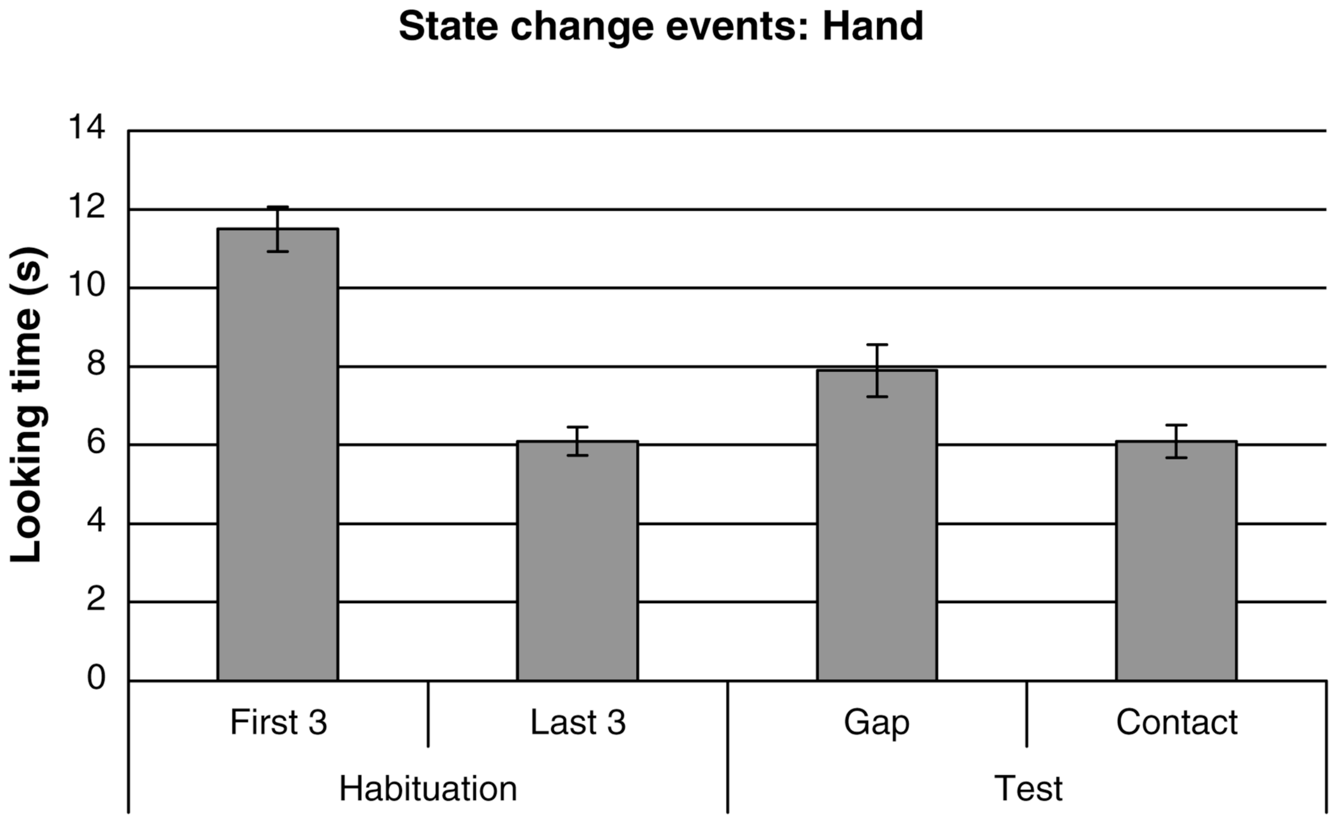

Figure 6.
Mean looking time (+ 1 *SE*) to the habituation and test trials in the state change events (collapsed across the color change/music and breaking conditions) when the potential agent was a human hand (Experiment 3).

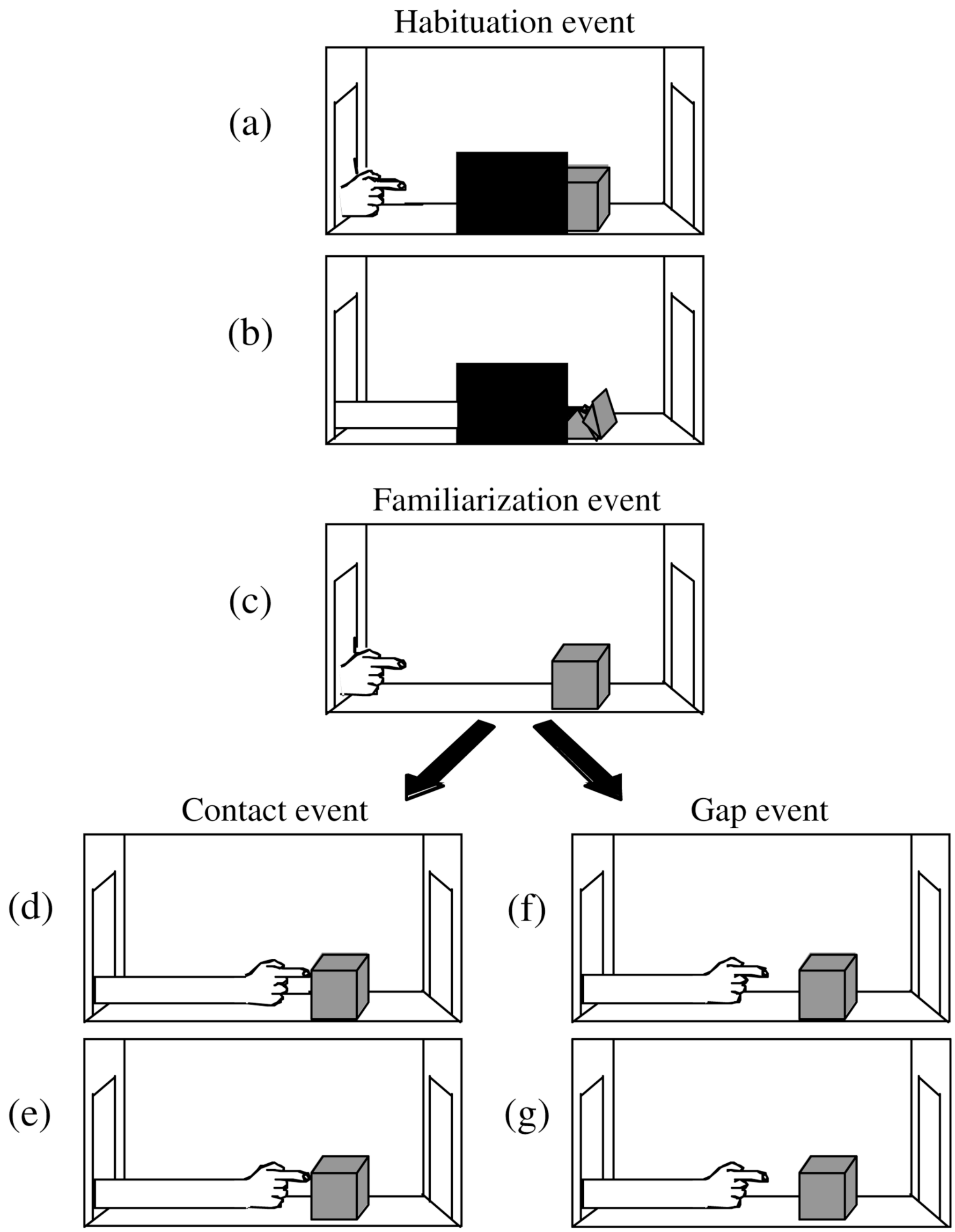

Figure 7.
Schematic depiction of the procedure for Experiment 4.

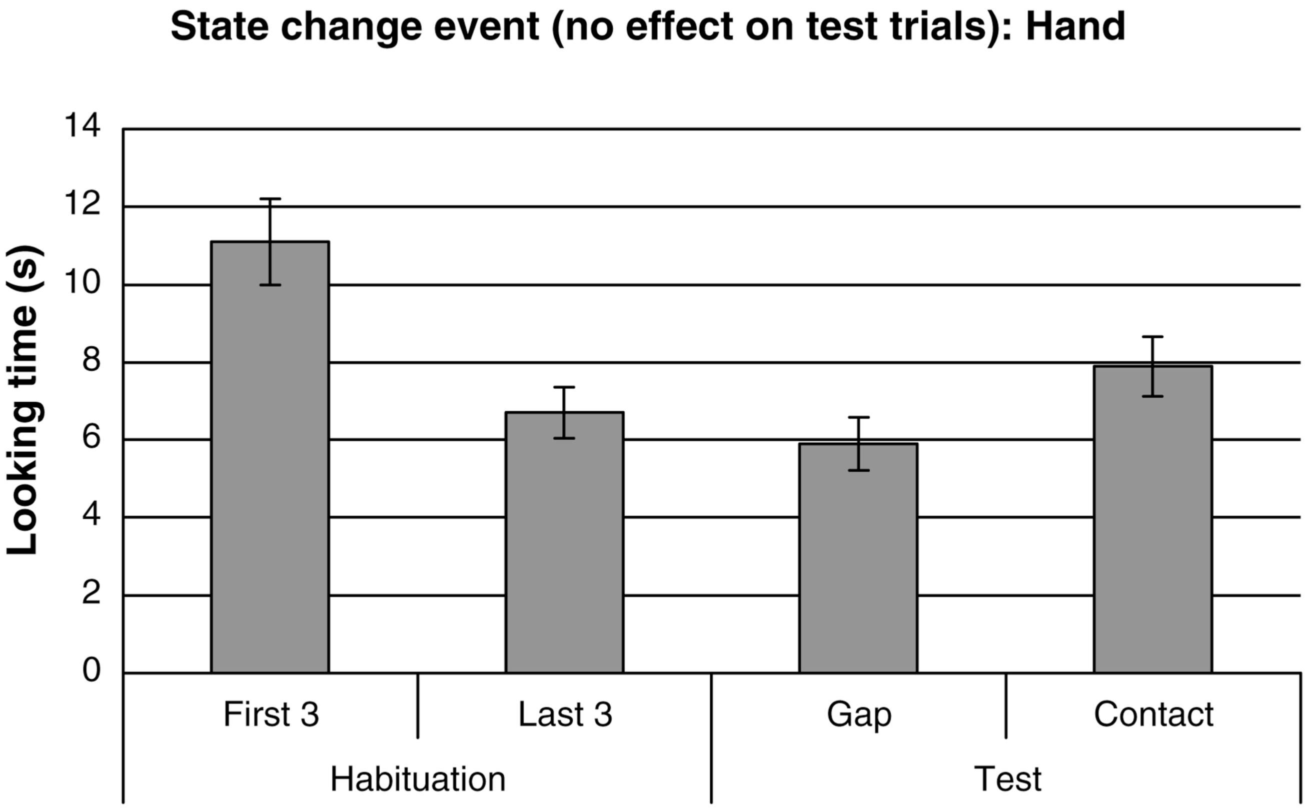

Figure 8.
Mean looking time (+ 1 *SE*) to the habituation and test trials in Experiment 4, when the state change did not occur during the test trials.

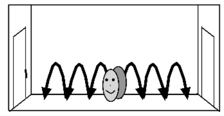

Figure 9.
Schematic depiction of the familiarization event in Experiment 5, in which the novel agent with a face displayed self-propelled motion.

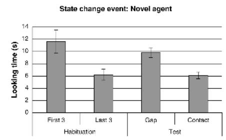

Figure 10.
Mean looking time (+ 1 *SE*) to the habituation and test trials in Experiment 5.