Does causal action facilitate causal perception in infants younger than 6 months of age?

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Abstract

Previous research has established that infants are unable to perceive causality until 6½ months of age. The current experiments examined whether infants’ ability to engage in causal action could facilitate causal perception prior to this age. In Experiment 1, 4½-month-olds were randomly assigned to engage in causal action experience via Velcro sticky mittens or not engage in causal action because they wore non-sticky mittens. Both groups were then tested in the visual habituation paradigm to assess their causal perception. Infants who engaged in causal action – but not those without this causal action experience – perceived the habituation events as causal. Experiment 2 used a similar design to establish that 4½-month-olds are unable to generalize their own causal action to causality observed in dissimilar objects. These data are the first to demonstrate that infants under 6 months of age can perceive causality, and have implications for the mechanisms underlying the development of causal perception.

Introduction

The perception of causality is widely regarded as one of the cornerstones of infants’ developing ability to understand the world around them. Piaget (1954), for example, proposed that between 4 and 7 months of age infants start to produce secondary circular reactions whereby they repeat actions that caused an effect in the world. Over the last two decades, developmental scientists have built on Piaget’s idea and developed a large database that charts the emergence of causal perception in the first year of life.¹ This research has demonstrated repeatedly that infants older than approximately 6 months of age respond to simple Michotte-like launching events – in which a simple geometric object hits and apparently makes another simple object move – in terms of causality (e.g. Cohen & Oakes, 1993; Oakes & Cohen, 1990; Leslie, 1984; Leslie & Keeble, 1987). Infants younger than 6 months, however, respond to such events only in terms of their continuity or spatio-temporal properties (Cohen & Amsel, 1998; Desrochers, 1999). Why is it that infants fail to perceive such events as causal before 6 months of age? And could, as Piaget suggested, their action in the world facilitate their ability to respond to simple events as causal? These questions were addressed in the experiments reported here.

A number of empirical studies on causal perception have established that infants undergo a clear developmental progression during the first year of life. In many of these studies, infants are habituated and tested with simple direct launching, delayed launching, or noncontact events with geometric figures based on those developed by Michotte (1963). Leslie and Keeble (1987), for example, found that 6½- to 7-month-olds who were habituated to a direct launching event recovered visual attention more to the reversal of the event than infants who were habituated to a delayed launching event. The authors surmised that infants in the direct launching event were responding to the causal change in agent–recipient relations. Oakes and Cohen (1990; Cohen & Oakes, 1993), using a variant on this design, found that 6-month-olds did not discriminate causal from non-causal events but that 10-month-olds discriminated causal from non-causal events and treated different non-causal events as equivalent. Finally, Cohen and Amsel (1998) and Desrochers (1999) found that 3½-, 4- and

¹ Although we, as others have done previously, use the term ‘causal perception’ throughout this manuscript, it is plausible that infants engage in some kind of causal learning during these experiments. It is unlikely, in our view, that this is akin to the causal reasoning observed in older children (e.g. Gopnik & Sobel, 2000) but we cannot eliminate the idea that infants’ behavior is underpinned by cognitive abilities as well as perceptual ones.
5½-month-olds responded to direct launching, delayed launching, and non-contact events not in terms of causality but rather their continuity and spatio-temporal cues.

It currently remains unknown why infants younger than 6 months of age are unable to perceive causality in simple causal events. One perspective is that they lack the information-processing abilities needed to encode the relatively complex interaction of objects in such events (Cohen & Amsel, 1998). According to Cohen (1991), systematic developmental changes in how infants process visual information dictate to which aspects of a launching event they are capable of attending. Cohen (1991) suggested that infants are initially able to process only simple features of objects, such as shape and type of motion, which may explain why 4-month-olds attended to the continuity of movement of the stimuli in Cohen and Amsel’s (1998) study. According to Cohen (1991), infants are able to process relations among object features at around 5 to 7 months of age, which allows them to begin processing the physical properties of the events as well as the individual objects involved in the events. By 7 to 10 months of age, infants can process relationships among different objects and their actions and integrate them into whole events, allowing them to perceive causality (Oakes & Cohen, 1990) or causation-at-a-distance (Schlottmann & Surian, 1999).

An alternative view for infants’ inability to perceive causality at 6 months of age was presented by Leslie (1994, 1995). Leslie (1994, 1995) theorized that infants possess three innately derived modules that, in combination, allow infants rapidly to develop an understanding of the physical (theory of body), psychological (theory of mind), and cognitive properties of animates and inanimates. According to this view, infants’ failure to perceive causality in the first 6 months of life is because the appropriate physical causality module has not yet been triggered at this age. It is unclear, however, how and when the kinds of modules proposed by Leslie (1995) are ‘triggered’ by certain kinds of input, or how specific modules but not others are triggered by specific inputs, especially when events involve both physical and psychological causality (for a discussion see Rakison & Poulin-Dubois, 2001, and Schlottmann, 2000).

An alternative hypothesis, which we propose here, is that infants younger than 6 months of age are capable of perceiving causality; however, the simple events with geometric figures they are typically shown in the laboratory are too different from the causal events with which they are familiar (for a similar proposal see Baillargeon, Kotovsky & Needham, 1995). In other words, infants prior to 6 months of age are sensitive to the causal outcome of their own actions – as Piaget suggested – but they are unable to generalize from their perception of such real-world events to simple Michottian events. If this were the case, infants should be able to perceive causality when the simple Michottian events that they observe during habituation are more akin to those they have experienced in the real world, and in particular if they engage in causal action that is similar to that presented during testing.

The hypothesis that infants’ action in the world mediates their perception and cognition is consistent with recent research by Needham and colleagues (Needham, Barrett & Peterman, 2002; Sommerville, Woodward & Needham, 2005). Needham et al. (2002), for example, found that 3-month-olds who wore Velcro covered mittens – allowing them to ‘grasp’ objects – later increased their exploration of novel objects when they were no longer wearing the mittens. In a similar vein, Sommerville et al. (2005) found that 3-month-olds who interacted with objects via sticky Velcro mittens – but not those without such action experience – interpreted an adult’s reach for the same objects as goal-directed. Similar effects of action on perception and cognition have recently been reported in a number of domains and a wide range of ages (e.g. Cicchino & Rakison, 2008; Melzoff & BROOKES, 2008; Ping & Goldin-Meadow, 2008).

It is currently unclear how infants’ action in the world mediates their perception and cognition (see Rakison & Woodward, 2008). There are currently three main hypotheses about the mechanisms that mediate this relationship. First, it has been proposed that new attentional strategies are learned through motor action, which change the kind of information that infants encode (Campos, Anderson, Barbu-Roth, Hubbard, Hertenstein & Witherington, 2000; Cicchino & Rakison, 2008). Second, it has been posited that proprioceptive input from infants’ own actions is an important additional source of perceptual information (Melzoff & Brookes, 2008; Sommerville et al., 2005). Third, causal action experience may activate mirror neurons, which are neural systems that represent both the infant’s own actions as well as observed actions. This would allow infants to generalize from their own experiences to those of others (Bertenthal & Longo, 2007; Decety & Grezes, 1999).

The goals of the current experiments were twofold. First, the experiments adopted a similar approach to Needham et al. (2002) and Sommerville et al. (2005) to examine whether infants younger than 6 months of age can perceive causality in simple events after they are given real-world experience of causal action. Second, the experiments were designed to provide insight into the mechanism that mediates the relationship between action and perception; that is, if infants’ causal perception is improved by a brief phase of action experience, then it is important to examine what it is about this experience that facilitated their behavior. Prior to habituation with simple Michottian events to test causal perception, infants wore mittens that were covered in Velcro or not covered in Velcro and allowed to interact with balls that were similarly covered or not covered in Velcro. In Experiment 1, we tested whether 4½-month-old infants’ action experience with mittens and balls that matched

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those seen during habituation – the mittens were the same color as the agent and the balls were the same color as the recipient – facilitated causal perception. In Experiment 2, we examined whether 4½-month-old infants’ action experience with the mittens and balls generalized to perceptually dissimilar causal events (e.g. from blue mittens and yellow cubes to red agents and green recipients).

Experiment 1

In this experiment, infants were randomly assigned to either a condition in which they interacted with green balls while wearing red Velcro sticky mittens or a condition in which they wore non-sticky red mittens that did not allow them to apprehend the balls. Infants in both conditions were then habituated and tested with the same launching and non-contact events with a red ball and a green ball. The habituation event was a simple launching event in which a red ball hit a green ball that then moved off-screen. All three test events were presented in the opposite direction to the habituation event: one depicted a launching event with the agent and recipient roles reversed (i.e. the green ball hit the red ball), one depicted a non-causal event (i.e. the green ball moved toward but did not contact the red ball), and one depicted a familiar event (i.e. the red ball hit the green ball). This design combines two previous methods for testing causal perception in infants, the reversal of stimuli design (see Leslie & Keeble, 1987) and within-group comparison design (see Cohen & Oakes, 1993). It was predicted that if real-world causal action facilitates causal perception, infants in the sticky mittens condition – but not those in the non-sticky mittens condition – would respond to the events in terms of their causality and look longer when the roles of the objects were reversed relative to the familiar test trial.

Method

Participants

The participants were 20 healthy full-term 4½-month-olds in the sticky mittens condition (mean age 4 months 16 days; range = 3:22 to 5:6) and 20 healthy full-term 4½-month-olds in the non-sticky mittens condition (mean age 4 months 16 days; range = 3:21 to 5:13). There were an equal number of males and females in each condition. The majority of infants were White and of middle socioeconomic status. Data from an additional 24 infants were excluded from the final sample, 10 because of failure to habituate (six from the sticky mittens condition, four from the non-sticky mittens condition), two because of looking more than 2 SD beyond the condition mean, five due to fussing or crying, three due to experimenter error, and two because of technical problems. Infants were recruited through birth lists obtained from a private company and were given a small gift for their participation.

Procedures and stimuli

Action task

Infants sat on their caregiver’s lap, supported by the waist, in front of a table at chest level. A pair of cotton mittens were then placed on the infant’s hands: In the sticky mittens condition, the mittens were covered in Velcro; in the non-sticky mittens condition, the mittens were unmodified. The Velcro mittens were similar to those created by Needham et al. (2002; see also Somerville et al., 2005) and allowed infants to make contact with, and pick up, the balls through swiping or batting. A tray of four balls (each approximately 3 cm in diameter) was then placed on the table in front of the infant. The balls were covered in Velcro in the sticky mittens condition but not in the non-sticky mittens condition. In both conditions, the mittens were red and the balls were green. In the non-sticky mittens condition, the balls were glued to the tray so that they could not move even if an infant made contact with them. The infants were allowed freely to interact with the provided toys for 180 s. If the infants made contact with a ball in the sticky mittens condition, the experimenter waited 10 seconds to remove the ball from the mitten. The ball was then replaced in the tray by the experimenter. After 180 s, the tray with the balls was removed from sight and the mittens were taken off the infant.

Habituation task

After the action task was completed, infants in both conditions participated in the same visual habituation procedure. The habituation and test events, which are illustrated in Figure 1, were animated events shown on a computer screen (size: 14.2 in × 24 in; distance: 24 inches) and created with Macromedia Director 8.0 for PC. Infants were habituated to a simple Michottian launching event in which a red ball, which was initially out of sight and off-screen, moved horizontally across the screen from left to right and contacted a green ball that was located in the center of the screen. On contact, a ‘ding’ noise was heard, the red ball stopped moving, and the green ball immediately began moving to the right and did so until off-screen. The length of time it took each event to be completed was 8.0 s and each event could be repeated up to three times per trial. Individual presentations of each event were separated by a blue screen that descended and ascended over a period of approximately 2 s. Each individual causal event, including the blue screen, therefore lasted 10 s.

After looking time to a block of three trials reduced below 50% of the first three looking trials, infants were presented with three test events. The events are illustrated in Figure 1. The familiar test event was identical to the
habituation event except that the balls moved from right to left across the screen. That is, it was a causal event in which a red ball hit a green ball but it was reversed in direction from the habituation events. The causal switch event was similar to the familiar test event but the position of the green and red was changed; that is, the green ball moved right to left from off-screen until it contacted the red ball, which then moved. The non-causal switch event was similar to the causal switch event except that the green ball stopped before contacting the red ball, which then started to move after a 1 s delay. To maintain consistency across the test trials, a ‘ding’ sound was heard during the non-causal event when the second object started to move. Note that all three test events involved a change in spatio-temporal properties – the balls moved from right to left instead of left to right – but one preserved the causal roles from the habituation events, one changed the causal roles from the habituation events, and one involved a switch from a causal to a non-causal event. The order of the test events was counterbalanced across 18 infants in each condition and then randomly selected for the final two infants in each condition.

Procedure

Each infant sat on their caretaker’s lap in front of a computer screen (size: 14.2 in × 24 in; distance: 24 inches). During the habituation and test phase, each event was presented until the infant visually fixated away from the monitor for over 1 s or until 30 s of uninterrupted looking had elapsed. A green expanding and contracting circle on a black background with a synchronous bell sound was presented prior to the first habituation trial and prior to every subsequent trial. The primary experimenter observed the infant via a video feed from a camera placed directly behind the computer monitor and coded the looking time behavior online by pressing and releasing a preset keyboard key. A second judge who was blind to the hypothesis and which trial was presented recoded the looking times from a videotape of the session. For the two experiments reported here, the Pearson product-moment pairwise correlation between the two coders was > .97 and the mean difference between the two coders’ scores was < 0.17 s, p > .80.

Predictions

It was predicted that infants in the sticky mittens condition would perceive the habituation events as causal – because of their action experience with the balls – and therefore look longer at the causal switch and non-causal switch test trials than at the familiar test trials. That is, infants should look longer at the causal switch event relative to the familiar event because the agent–recipient roles are reversed and longer at the non-causal event than the familiar because one includes a causal launch and the other does not. It was also predicted that infants in the non-sticky mittens condition would not perceive
the habituation events as causal and would therefore look longer at the discontinuous test trial event – the non-causal switch trial – than at the familiar test trial (as in Cohen & Amsel, 1998) but would look equally long at the causal switch and familiar test trials because they both have continuous motion. In other words, if infants did not perceive the habituation events as causal then they were expected to respond only to the continuous or discontinuous nature of the test trials.

Results

The first analyses compared the number of habituation trials and the total looking time during habituation for infants in the sticky mittens and non-sticky mittens conditions. The analyses revealed that infants in the sticky mittens condition ($M = 7.7$, $SD = 2.45$) required fewer trials to habituate than infants in the non-sticky mittens condition ($M = 9.55$, $SD = 2.86$), $t(38) = 2.20$, $p < .05$. However, although infants in the sticky mittens condition ($M = 71.43$, $SD = 34.11$) generally accumulated less looking time during habituation than infants in the non-sticky mittens condition ($M = 97.85$, $SD = 69.95$), this effect was not significant, $t(38) = 1.52$, $p > .1$.

To test the predictions outlined above, a series of planned comparisons were used to examine infants’ looking times to the causal switch and the familiar test trials and to the non-causal switch and familiar test trials. (For discussions of the validity of this procedure, and why it is unnecessary to perform omnibus ANOVAs on such data, see Howell, 1996; Rosenthal, Rosnow & Rubin, 2000; and Wilcox, 1987.) The data are presented in Figure 2. Planned comparisons for the sticky mittens condition revealed that looking times to the causal switch test trial ($M = 34.11$, $SD = 7.7$), $t(38) = 4.98$, $p < .05$, $\eta^2_p = .21$. Planned comparisons for infants’ looking times to the test trials in the non-sticky mittens condition showed that infants looked significantly longer at the non-causal switch test event ($M = 9.37$, $SD = 9.32$) than the familiar test event ($M = 6.25$, $SD = 4.58$), $F(1, 19) = 4.54$, $p < .05$, $\eta^2_p = .19$. Looking times to the causal switch test event ($M = 7.63$, $SD = 7.31$) and the familiar test trial were not reliably different, $F(1, 19) = 1.44$, $p > .2$, $\eta^2_p = .07$.

The next set of analyses compared infants’ looking at the three test trials to their last habituation trial. The rationale for this analysis was to determine whether infants responded to the surface features of the events (i.e. the change in direction) or to the causality in the events and the causal roles played by each object. Looking time to the last habituation event is, by definition, generally low (see Cohen & Menten, 1981), and it is inappropriate to use as the ‘familiar’ event in the main statistical analysis. It is nevertheless a useful measure in this case to examine whether infants responded only to the perceptual cues in the events (i.e. their direction) rather than the causality inherent in them. The analyses for the sticky mittens condition revealed that infants looked equally long at the last habituation event ($M = 4.68$, $SD = 3.68$) and the familiar event ($M = 4.78$, $SD = 2.65$), $F(1, 19) = 1.44$, $p > .2$, $\eta^2_p = .07$.

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![Figure 2](image-url) **Figure 2** Infant looking times to the three test events in the sticky mittens and non-sticky mittens conditions in Experiment 1. Infants in the sticky mittens condition looked significantly longer at the causal switch test event and non-causal switch test event than at the familiar event. Error bars represent standard error.
looked equally long at the balls during the action phase, \( t(33) = 0.91, p > .3 \). A second analysis revealed that infants in the sticky mittens condition (\( M = 14.39, SD = 48.89 \)) touched the balls equally as often as infants in the non-sticky mittens condition (\( M = 12.88, SD = 15.28 \)), \( t(33) = 0.38, p > .7 \). There was also no significant difference in the number of different balls that were touched in the two conditions, \( p > .3 \). Thus, the different patterns of looking found across the sticky and non-sticky mittens conditions could not be attributed to greater overall looking at, or touching of, the balls during the action phase.

Lastly, we performed a series of correlational analyses to examine the relation between infants’ habituation responses (i.e. total number of habituation trials and total looking during habituation) and various aspects of their behavior during the action phase of the experiment (for similar analyses see Sommerville et al., 2005). For the sticky mittens condition, the number of habituation trials was negatively correlated with the time that infants looked at the balls when they stuck on the mittens, \( r = -0.51, p < .05 \). Thus, the more that infants looked at the balls while they were on the mittens, the less time they required to habituate. The number of habituation trials was not, however, related with the amount of time that infants looked at the balls when not on the mittens, \( r = -0.20, p > .4 \), or how many times the infants made the mittens contact the balls, \( r = .16, p > .5 \). The total amount of looking time during habituation was not significantly correlated with any aspects of infants’ behavior during the action phase, all \( ps > .2 \). Finally, the analyses revealed no significant correlations between habituation responses and behavior during the action phase for infants in the non-sticky mittens condition, all \( ps > .3 \). These findings suggest that, as in Sommerville et al. (2005), the behavior of infants only in the sticky mittens condition during the habituation trials was related to their action experience during the action phase of the experiment.

Discussion

The current experiment is the first to show that infants younger than 6 months of age are capable of perceiving causality in simple launching events. Infants who interacted with objects by wearing sticky Velcro mittens increased visual fixation, following habituation with a direct launching event, to an event in which the agent–recipient relation changed as well as to a non-causal event. In contrast, infants who could not interact with the balls because they wore non-sticky mittens increased visual fixation in the test phase only to an event without continuous movement. There was also a marked difference in the looking times during habituation for the two groups of infants: the number of habituation trials was significantly lower for those in the sticky mittens condition relative to those in the non-sticky mittens condition. In addition, infants’ behavior in the action phase of the experiment for the sticky mittens condition was related to their habituation performance. In conjunction, these different patterns of behavior during the habituation and test trials provide strong evidence that infants in the sticky mittens condition responded to the simple computer animated events in terms of causality, and they did so because of their brief experience engaging in a causal action themselves. Infants in the non-sticky mittens condition, in contrast, responded to the lower-level perceptual characteristics of events such as continuous versus discontinuous movement (see Cohen & Amsel, 1998).

Experiment 2

The results of Experiment 1 suggest that infants’ causal perception was facilitated by a short period of action experience with mittens and balls that matched in color the objects seen during habituation. Infants in the two conditions during the action phase looked equally long at the balls and touched them equally often. This suggests that it was the causal interaction with the balls – and perhaps the closer scrutiny that infants could pay to balls that were attached to the mittens – that facilitated their causal perception. Nonetheless, it remains to be seen in what way this action experience produced a change in infants’ ability to perceive causality. There are at least three, not necessarily mutually exclusive, mechanisms that mediate this relationship (see Rakison & Woodward, 2008). First, proprioceptive input from infants’ actions – in this case, causing the balls to move with the mittens and hands – may be an important additional source of perceptual information (Meltzoff & Brooks, 2008; Sommerville et al., 2005). Second, causal action experience may activate neural systems that represent both the infant’s own actions as well as observed actions – often labeled mirror neurons – which allows them to generalize from their own experiences to those that they see in the world (Bertenthal & Longo, 2007; Decety & Grezes, 1999). Third, infants may learn new attentional strategies through motor action, which changes the information that they encode (Campos et al., 2000; Cicchino & Rakison, 2008). Thus, sticky mittens experience may have caused greater attention to the balls and to the causality involved in infants’ interaction with them. This in turn may have led infants to encode that red objects cause green objects to move.

Experiment 2 was designed to shed light on which of these mechanisms may have facilitated infants’ causal perception in the first experiment. Infants at 4½ months of age were given action experience similar to that in Experiment 1 except that the color of the Velcro mittens and the shape and color of the toys were different from the objects presented during habituation. Thus, infants in this experiment wore blue Velcro mittens and played with yellow Velcro-covered cubes. The infants were then habituated and tested with the same events as those used in Experiment 1. The non-sticky mittens condition was
not included in this experiment because there was no reason to expect it to facilitate causal perception if the same condition did not do so in Experiment 1.

It was predicted that infants would generalize from their action experience to the habituation events – as they did in Experiment 1 – if proprioceptive input or mirror neurons mediate the relationship between action and perception. According to these accounts, infants’ action per se is crucial rather than the similarity of the objects in the action phase and the habituation phase. It was also predicted that infants would fail to generalize from their action experience to the habituation events if the action phase facilitates their attentional strategy and subsequent encoding. Thus, infants’ action experience in this experiment should cause them to encode that blue objects cause yellow objects to move and this should not transfer to the red and green balls in the habituation and test events.

Method

Participants

Sixteen healthy, full-term 4½-month-old infants (mean age 4 months 16 days; range = 3;27 to 5;14) were recruited for participation in this study. There were nine girls and seven boys. The data from four infants were excluded from the final analyses because of failure to habituate (n = 1), parental interference (n = 1), fussing (n = 1), and looking for the maximum trial length at all three test trials (n = 1). Infants were recruited from birth lists obtained from a private company and were given a small gift for their participation.

Procedures and stimuli

Action task, habituation and test stimuli

The action task was identical to the sticky mittens condition in Experiment 1 except that the infants wore blue Veleró mittens and the objects were four yellow cubes (each weighing approximately 0.3 ounces and having 3.5 cm sides). Infants were allowed to interact freely with the provided toys for 180 s, after which the tray with the cubes was removed from sight and the mittens were taken off the infant. All other aspects of the experiment – including the habituation and test stimuli – were the same as Experiment 1.

Results

Initial analyses compared the habituation rate of infants in this experiment to those in Experiment 1. There was no difference between the sticky mittens condition of Experiment 1 and the current experiment in the number of trials required to reach habituation (Experiment 1, \( M = 7.70, SD = 2.45 \); Experiment 2, \( M = 7.57, SD = 3.18, t(34) = .14, p > .8 \)) or the total amount of looking time during habituation (Experiment 1, \( M = 79.90, SD = 46.65 \); Experiment 2, \( M = 81.39, SD = 86.94, t(34) = .06, p > .9 \)). Likewise, there was no difference between the non-sticky mittens condition of Experiment 1 and the current experiment (number of trials: Experiment 1, \( M = 9.05, SD = 2.91 \); Experiment 2, \( M = 7.57, SD = 3.18, t(34) = 1.69, p > .1 \); total amount of looking: Experiment 1, \( M = 97.8, SD = 69.95 \); Experiment 2, \( M = 81.39, SD = 86.94, t(34) = 0.62, p > .5 \)).

As in Experiment 1, planned comparisons were used to compare infants’ looking to the familiar test trial relative to the other two test trials. The analyses revealed that infants looked equally long at the familiar test event (\( M = 8.01, SD = 7.44 \)) and the causal switch test event (\( M = 8.18, SD = 7.95, F(1, 15) = 0.01, p > .9, \eta^2_p = .01 \)). Likewise, they looked equally long at the familiar event and the non-causal switch test event (\( M = 6.83, SD = 6.37, F(1, 15) = 0.32, p > .5, \eta^2_p = .02 \)). Infant looking times for the three test events are presented in Figure 3.

As in Experiment 1, a final set of analyses compared looking times to the last habituation trial to that on the three test events. Consistent with the findings for the non-sticky mittens condition in Experiment 1, infants looked significantly longer at the familiar test trial (\( M = 8.01, SD = 7.44 \)) than the last habituation trial (\( M = 4.39, SD = 6.34, F(1, 15) = 5.24, p < .05, \eta^2_p = .26 \)). Infants also looked longer at the causal switch trial (\( M = 8.18, SD = 7.95 \)) than at the last habituation trial, \( F(1, 15) = 5.39, p < .05, \eta^2_p = .26 \); however, they looked equally long at the non-causal switch test trial and the last habituation trial, \( F(1, 15) = 2.80, p > .1, \eta^2_p = .16 \).

Action phase

A final series of analyses examined the relation between the number of habituation trials and total looking during habituation with their behavior during the action mittens phase of the experiment. In contrast to Experiment 1, the looking times to the three test events in Experiment 2. Error bars represent standard error.
analyses revealed no significant correlation between performance during the habituation trials and how long infants looked at the cubes when they stuck on the mittens, the amount of time that infants looked at the cubes when not on the mittens, or how many times infants made the mittens contact the cubes, all $p$s > .2. Finally, to examine whether infants in this experiment engaged in less causal action than those in Experiment 1, we compared the number of times the balls became attached to the mittens in this experiment relative to the sticky mittens condition from Experiment 1. The analysis revealed no significant difference between the two conditions, $t(31) = 1.51, p > .1$.

**Discussion**

Experiment 2 was designed to examine the mechanisms by which infants’ action experience facilitated their ability to perceive causality in Experiment 1. The rationale for the experiment was to determine whether infants’ action experience allows them to learn something about causality in an abstract sense – that is, agents cause recipients to change physical state – or something more specific about which things cause which other things to change state (e.g. blue things cause yellow things to move). The results of the experiment suggest that the latter interpretation is more accurate: Infants failed to generalize their causal action experience with blue mittens and yellow cubes to a causal event with red circular agents and green circular recipients. These data provide tentative support for the notion that action experience facilitates attentional strategies and subsequent encoding because the alternative mechanistic explanations – that proprioceptive input or mirror neurons mediate the relationship between action and perception – imply that infants would have generalized from the action phase to the dissimilar objects in the habituation and test phase. It is possible that proprioceptive input or mirror neurons may play a role in such learning under other conditions; for example, the fact that infants wore mittens may have interfered or muffled the proprioceptive input that they typically receive with their hand. Regardless, it is difficult to infer too much from negative results, and additional research is needed before strong conclusions can be drawn about the mechanism that mediates the link between action and perception. In particular, it is plausible that infants would generalize more readily from the action phase of the experiment if the agent in the habituation phase possessed cues to animacy and the recipient did not possess such cues (see e.g. Schlottmann & Ray, 2010). We are currently testing this hypothesis using a human hand as the agent in the habituation trials.

It is unclear why infants in the current experiment did not respond similarly to those in the non-sticky mittens condition in Experiment 1. Based on the findings of Experiment 1 and Cohen and Amsel (1998), it was expected that if infants did not respond to the causality in the events then they would look longer at a discontinuous event than at the familiar event. One plausible explanation is that the differences in the objects presented in the action phase and the habituation phase of the experiment caused infants to attend more to the appearance of those objects than the motion in the events. That is, infants may have been overly influenced by the different color of the real balls and mittens relative to the objects in the habituation events and consequently failed to encode the motion in those habituation events. This behavior would lead infants to look equally long at all three test events, which was the observed pattern. It does not, however, undermine the finding that infants failed to generalize from a real-world causal event in which they participated to a different causal event in the habituation phase of the experiment.

**General discussion**

The two experiments reported here were designed to explore the relation between 4½-month-old infants’ causal action experience and their ability to perceive causality in simple launching events. Experiment 1 indicated that infants at 4½ months of age perceived launching events as causal when they were given a brief action experience phase with mittens and balls that mirrored those seen during habituation and test. However, infants of the same age did not perceive launching events as causal when they were given comparable action experience but were unable to perform a causal action themselves. Experiment 2 revealed that 4½-month-olds did not perceive causality when their causal action experience did not match perceptually the causal launching events they saw during habituation.

These experiments are the first to show that infants younger than 6 months of age can perceive simple direct launching events as causal (cf. Baillargeon et al., 1995). Previous research on this issue has shown that infants at 6½ months – but not younger infants – can discriminate causal from non-causal events even when the objects are complex and variable (Leslie & Keeble, 1987; Oakes & Cohen, 1990; Cohen & Oakes, 1993). Moreover, the two studies that have tested infants under 6 months of age have shown that 3½-, 4- and 5½-month-olds responded to direct launching, delayed launching, and non-contact events in terms of their continuity and spatio-temporal cues (e.g. Cohen & Amsel, 1998). The current experiments extend these findings because they show that infants at 4½ months of age can perceive causality following only a brief phase in which they are allowed to engage in causal action themselves. That such a brief period of action facilitates causal perception suggests that infants at 4½ months of age possess the ability to perceive launching events as causal and of assigning agent and recipient roles to the first and second objects in such events.
The results of the study have potential theoretical implications with regard to infants’ developing ability to perceive causality. Cohen, Oakes and colleagues (Oakes & Cohen, 1990; Cohen & Oakes, 1993; Cohen & Amsel, 1998) have proposed that 6½-month-old infants’ emerging ability to perceive causality is based on improving information-processing skills, whereas Leslie (1995; Leslie & Keeble, 1987) has suggested that infants possess an encapsulated innate perceptual mechanism, or module, that processes mechanical agency and is ‘triggered’ around 6 months of age by the appropriate input. The experiment reported here is more consistent with the first of these views. In contrast to Leslie’s claim, infants at 4½ months of age perceived the presented events as causal and this ability was affected by outside influence in the form of action. At the same time, the results suggest that a caveat is required for the perspective forwarded by Oakes and Cohen (1990; Cohen & Oakes, 1993). They argued that the information-processing abilities required to perceive causality are not in place until 6 months of age; yet the current data show that such abilities are present in infants as young as 4½ months of age. We suggest that the abstract nature of the events used in previous research may have prevented infants from responding to launching events as causal and from discriminating causal from non-causal events. This explanation is supported by parallel findings on infants’ responses to goal-directed events; 6-month-olds respond to a hand reaching for an object – but not an inanimate object with digits – as goal-directed action (Woodward, 1998). Thus, one potential future avenue of research is to explore whether infants under 6 months of age respond to highly familiar events (e.g. a hand moving a bottle) as causal. This approach may also help to determine when infants begin to extract a more abstract notion of causality that ultimately develops into the more advanced causal reasoning observed in preschoolers (Gopnik & Sobel, 2000).

It could be argued that infants’ looking times in the sticky mittens condition were not the result of causal perception but rather low-level changes in the events from the habituation to the test phase. There is good reason, however, to reject this claim. The crucial looking pattern for infants in the sticky mittens condition was that they looked longer at the causal switch test trial than at the familiar test trial. However, there were an equivalent number of low-level perceptual changes between the habituation trials, on the one hand, and the causal switch test event and the familiar test event, on the other hand. The first object on screen was different from that seen in the habituation trials in the causal switch test event (i.e. green) but not the familiar test event (i.e. red) (for evidence that 4-month-olds are sensitive to serial order, see Lewkowicz & Berent, 2009). The placement of the objects on screen was different from the habituation trials in the familiar test event (i.e. red object on right side and green on left side) but not in the causal switch test event. Thus, the causal switch test event and the familiar test event each included two low-level perceptual changes from the habituation event (i.e. direction change plus one other). In our view, it is possible but unlikely that infants in the sticky mittens condition responded to one low-level perceptual change and not the other, and that infants in the sticky and non-sticky mittens conditions responded to different low-level perceptual changes.

A similar low-level argument could also be made about the effect of the first object that moved on screen. For example, it is possible that infants in the sticky mittens condition looked at the causal switch test trial not because of the change in causal roles but because they learned from the action phase about the order of the motion; that is, the green object moved first and not the red one. The infants in the non-sticky mittens condition, in contrast, did not respond to the change in order of motion because they did not learn this from the action experience phase. Consequently, infants in the non-sticky mittens condition reacted to the even more obvious change from continuous to discontinuous motion but not to the change in which object moved first. Although we cannot rule out this argument – and it is well established that infants are sensitive to temporal order of three non-delayed motions (Lewkowicz, 2004) – in our view the fact that the pattern of looking in Experiment 1 was predicted a priori and that our explanation about the relation between action and causal perception is significantly more parsimonious than these ‘low-level’ explanations of the data suggests that the pattern of looking found in the sticky mittens condition resulted from infants’ causal perception of the events.

The current data also add to a recently emerging literature on the causal relationship between self-produced action and perceptual and cognitive development (e.g. Campos et al., 2000; Cicchino & Rakison, 2008; Meltzoff & Brooks, 2008; Needham et al., 2002; Ping & Goldin-Meadow, 2008; Sommerville et al., 2005). These lines of empirical work have in common the notion that perceptual and cognitive development can only be understood fully by taking into account how they are affected by the child’s action in the world. The current experiments are the first attempt to identify the mechanism that mediates this causal relationship. The most promising candidates are that action causes the child to employ new attentional strategies which changes the information that is encoded (Campos et al., 2000; Cicchino & Rakison, 2008), that proprioceptive input from action is an additional type of perceptual input (Meltzoff & Brooks, 2008; Sommerville et al., 2005), and that there exists an action production—observation matching system (Bertenthal & Longo, 2007; Decety & Grezes, 1999).

The present experiments indicate that self-produced action can facilitate causal perception but this effect is limited to contexts in which infants’ action experience matches perceptually their visual experience. That is, Experiments 1 and 2 showed that infants generalized from actions involving red mittens and green balls – but
not from blue mittens and yellow cubes – to visual events with red balls and green balls. This finding suggests that infants in the action phase of Experiment 1 may have learned that red things cause green thing to move and generalized this to the perceptually similar objects in the visual habituation events. In contrast, infants in Experiment 2 may have learned that blue things cause yellow things to move, but they did not generalize this relationship to the red and green objects in the habituation events. It is possible that infants in Experiment 2 may have responded to the events as causal if they had been given additional action experience with the balls or if a wider range of shapes and colors for the balls and mittens were used. In our view, the second of these options has potential because it may allow infants to develop a more abstract representation about the identity of the agent and recipient in the causal events.

An important question is why 4½-month-old infants, who presumably have considerably more than 180 seconds’ experience of reaching and contacting objects in the real world, have not previously exhibited evidence of causal perception (e.g. Cohen & Amsel, 1998). The current data suggest that it is unlikely that this is due to insufficient information-processing abilities on the part of young infants, so why then do infants typically not show causal perception prior to 6 months of age? As noted by Piaget (1954), infants between 4 and 8 months start to engage in action experience as a causal agent by banging two objects together, and they continue to do so because of the inherent satisfaction of such action. We too suggest that this is a crucial step in infants’ ability to perceive causality, although at this point they perhaps view only themselves, and not others, as a causal agent.

In our view, it is only once infants start to learn that there are many things in the world other than themselves that can act as agents – which is presumably in place by 6½ months of age – that they may start to form a more abstract representation for ‘agency’ that can support causal perception in the lab. Until this point, however, infants may only exhibit causal perception in an experimental paradigm if what they see closely matches their own experience of causal events. Indeed, in the current experiments infants may have developed a representation that encapsulates a simple, specific aspect of causality such as ‘red produces green’s action’ rather than a complete understanding of how launching events operate (for a similar view see Schlottmann, Surian & Ray, 2009).

Thus, as we hypothesized earlier, infants younger than 6 months of age may be able to perceive events as causal in the real world but the Michotte-like stimuli in typical causal perception studies may be too abstracted from the causal events with which they are familiar. This is why infants in the sticky mittens condition of Experiment 1 showed evidence of causal perception – the stimuli in the action phase with which they gained causal experience were quite similar to those in the habituation phase of the study – but infants in Experiment 2 did not. This suggests that infants at 4½ months of age can form some kind of mental representation for causality that generalizes to other instances – after all, the action phase was not identical to the events presented during habituation – but this representation is not sufficiently abstract to generalize to significantly different contexts such as that in Experiment 2. Unfortunately, it also currently remains an open question when infants develop a sufficient representation of agency to support causal perception in the real world. To this end, we are currently testing whether 4½-month-olds exhibit this ability when habituated to more familiar causal events (e.g. a hand that causes a bottle to move).

This pattern of results suggests, albeit tentatively, that infants’ action experience facilitates their causal perception because it engenders new attentional strategies and encoding. As outlined earlier, in Experiment 2 it was predicted that infants would generalize from their action experience to the visual habituation events if proprioceptive input or mirror neurons mediate the relationship between action and perception. This prediction follows from the notion implicit in these perspectives that infants’ action per se is important in mediating this relationship rather than the similarity of the objects used in the action phase and seen in the habituation phase. However, the results of Experiment 2 suggest that this was not the case. The data instead were consistent with the attentional strategy and encoding view (Campos et al., 2000; Cicchino & Rakison, 2008) because they indicate that infants’ causal action alone is insufficient to produce a change in their causal perception. Rather, the action phase leads infants to encode the appearance of the objects in the action phase and use this information during the visual part of the task. Nonetheless, further work is required to establish whether this interpretation is accurate. For example, if the balls were moved to the mitten by an experimenter (rather than the infants reaching for them) it may be possible to tease apart the role of the infants’ action relative to their better encoding of the balls as a result of that action. Only once the mediating mechanism or mechanisms are identified will developmental scientists truly begin to understand the way in which input interacts causally across multiple domains.

In summary, the current experiments are the first to show that infants younger than 6 months of age can perceive simple launching events as causal. Infants at 4½ months of age showed evidence of causal perception following a brief period of action experience during which they could engage in causal actions themselves via sticky Velcro-covered mittens. The experiments are also the first to examine the mechanism that mediates the relationship between action and perception in infancy. The data suggest, albeit tentatively, that infants’ action may facilitate their perception because it leads to a change in attention and encoding (Campos et al., 2000; Cicchino & Rakison, 2008), which is then transferred to a visually based paradigm. The approach used here – combining an action phase with a perceptual task – has heuristic value because it suggests that some established perceptual and cognitive milestones could occur earlier if infants received the
appropriate real-world experience. Few researchers have adopted this approach as yet, though there are a small number of notable exceptions (e.g. Sommerville et al., 2005; Woodward, 1998). It remains to be seen how many other well-established findings in infant perception and cognition need similarly to be re-evaluated.

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