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The Effect of Action on Causal Perception in 3- and 4½-month-old Infants

Lauren Krogh
Carnegie Mellon University

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Abstract

Research has shown that infants perceive causality beginning at the age of 6 months. However, a recent study demonstrated that 4½-month-old infants perceive causality when they are given the ability to perform causal actions by wearing red mittens covered in Velcro that attach to Velcro on green toy balls. The current experiments examined whether the perceptually similarity between the objects infants interacted with and the stimuli used in the test events accounted for infant's perception of causality in these events. Results show that the particular objects used in the action task do not constrain 4½-month-old infants' perception of causality in simple launching events. The data also reveal that 3-month-old infants do not respond to simple launching events in terms of either causality or continuity, following action experience. Results are discussed in terms of the developmental progression of causal perception, as well as possible mechanisms underlying this development.

The Effect of Action on Causal Perception in 3- and 4½-month-old Infants

Perceiving cause and effect is an essential component of humans' understanding of the world around them. Piaget (1953) proposed that causal understanding emerges within the first year of life through a pattern of activity that he called a secondary circular reaction. According to Piaget, infants engage in a cycle of accidental action accompanied by perception of the effects of that action. This leads to further action – because infants are stimulated by their effect on the world – and ultimately results in cognitive development. Recently, developmental scientists have built upon Piaget's ideas, investigating both the time course of the development of causal perception in infancy as well as the role that agentive experience may play in facilitating infants' ability to perceive causality in simple events.

Developmental psychologists have long debated the origins of causal perception. Almost half a century ago, Michotte (1963) investigated adults' perception of causal illusions using a set of direct launching, delayed launching, and no collision stimulus events. In direct launching events, a simple object moved from left to right across a screen until it made contact with a second simple object, which moved immediately following the collision. Adults perceived such direct launching events as causal, and they perceived both delayed launching (in which there was a temporal delay between the collision and the time the second object moved) and no collision (in which the first object stopped moving before making contact with the second object) events as non-causal (Michotte, 1963). Studies that investigate infants' causal perception often employ habituation and test events similar to those used by Michotte. Based on several studies in which infants at 6½ months of age perceived launching events similarly to adults in terms

of causality, Leslie (1982, 1984, 1988, 1995; Leslie & Keeble, 1987) proposed that an innate perceptual module, which functions from infancy and is subject to little or no developmental change, is responsible for causal understanding. Several recent empirical studies, however, support an alternative explanation, providing evidence that causal understanding does undergo a developmental progression during the first year of life.

By 6 months of age, infants detect the internal structure of Michotte-like launching events in addition to changes on a lower, perceptual level (Leslie 1984). In Leslie's (1984; Experiment 1A) study, infants were habituated either to a direct launching event or to movement of a single object along the same trajectory. When tested on the reversal of these events, infants in the direct launching condition showed greater recovery of looking time to the reversal event compared to infants in the single movement condition. This provides evidence that infants at 6½ months of age are sensitive to changes in the submovements of direct launching events in addition to more global perceptual changes, such as a switch in spatial direction.

Leslie (1984) also demonstrated that 6½-month-olds infants detect causal relations in Michotte-like launching events and distinguish a causal event from other events sharing the same spatio-temporal characteristics. Leslie (1984; Experiment 2) habituated two groups of infants to different launching events, then tested the infants on launching events that contrasted with the habituation event in terms of both contact (whether or not the two objects physically touched) and the presence of a delay (whether or not the second object began moving immediately after the first object stopped moving). Thus, the two groups of infants saw two different pairs of habituation and test events that each shared the same spatial and temporal differences. One pair, however,

consisted of two non-causal events whereas the other pair consisted of a one causal and one non-causal event. Infants who were shown this second pair of events dishabituated more at test than infants shown two non-causal events, even though both pairs of events differed equally in their physical characteristics, indicating that infants at 6½ months of age are sensitive to causal relations.

Oakes and Cohen (1990) conducted a similar study to contrast 6- and 10-month-old infants' perception of the physical characteristics of launching events with their perception of causality. Unlike Leslie's study with 6½-month-olds, Oakes and Cohen (1990) found no evidence of causal perception at 6 months of age. In addition, Oakes and Cohen (1990) found that by 10 months of age, infants responded only to the causality of the events, treating different non-causal events as equivalent and no longer responding to their spatio-temporal differences as infants did in Leslie and Keeble's (1987) study. A later study by Oakes (1994) revealed that by 7 months of age infants respond to launching events based only on causality and not on differences in the spatial and temporal features of the events. In addition, studies by Cohen and Amsel (1998) with 4-, 5½-, and 6¼-month-olds revealed that even before responding to the spatio-temporal properties or causality of launching events, 4-month-olds respond to direct launching, delayed launching, and no collision events based solely on their continuity. By 5½ months of age, infants respond on the basis of spatial and temporal perceptual features of the events, as well their continuity, and at 6¼ months of age infants respond to causality as well as to the spatial and temporal features of the events (Cohen & Amsel, 1998).

The clear developmental progression evident in these studies of infants' response first to the continuity, then to the physical characteristics, and finally to the causality of

Michottian launching events, calls for an alternative to Leslie's innate modular account of infants' causal perception. Cohen (1988, 1991) proposed an information-processing explanation of infants' development of causal perception. According to Cohen (1991), systematic developmental changes in how infants process visual information dictate to which aspects of a launching event infants 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 later 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.

Cohen's information-processing explanation aligns well with the time course described by years of research into the developmental progression of infants' causal perception. Recent empirical findings, however, call for a reworking of Cohen's theory, suggesting that infants may be capable of perceiving causality at as young as 4½ months of age if first given laboratory experience performing causal actions (Rakison, 2009). Rakison proposed that infants are capable of perceiving causality and are sensitive to the causal effects of their own actions before 6 months of age. According to Rakison, infants are unable to generalize from their perception of real-world events to the simple Michottian events used in most laboratory studies because these events are too abstracted from the causal events with which infants are familiar. In Rakison's study, 4½-month-old

infants wore red mittens that were either covered in Velcro, giving infants the ability to perform causal actions by picking up green toy balls also covered in Velcro, or they wore smooth mittens that did not allow infants to engage in causal actions. After habituation to direct launching events involving a red ball moving left to right across the screen and colliding with a green ball, infants were presented with three test events. The familiar test event was a replica of the direct launching habituation event, except the objects now moved from right to left across the screen. The causal switch event changed the position of the red and green balls such that the green ball moved from right to left across the screen, contacting the red ball and causing it to move. The non-causal event was similar to the causal switch test event except that the green ball stopped before contacting the red ball, which then began moving after a 1s delay. Infants in both the Velcro and smooth conditions looked significantly longer at the non-causal test event than the familiar test event, which indicated that they could detect differences in the continuity of the events, as shown previously by Cohen and Amsel (1998). Importantly, however, only infants in the Velcro mitten condition, who performed causal actions prior to habituation, looked significantly longer at the causal switch test trial than the familiar test trial, indicating that they perceived the causality of the events.

Rakison's (2009) findings are another addition to a growing body of research into the effect that Piaget (1953) hypothesized, that infants' actions in the world affect their perceptual and cognitive development. Recent work has shown that even very young infants are able to learn from their own causal interventions (Bojczyk & Corbetta, 2004; Cicchino & Rakison, 2008; Needham, Barrett, & Peterman, 2002). Needham et al. (2002), for example, demonstrated that giving pre-reaching 3-month-olds the ability to

interact with toys via Velcro-covered mittens resulted in more sophisticated object exploration by these infants when they were no longer wearing the mittens compared to infants not given such experience. Further evidence suggests that infants' are also able to relate their own experience in the world to that of others (Meltzoff & Brooks, 2008; Sommerville, Woodward, & Needham, 2005). For instance, Sommerville et al. (2005) found that 3-month-olds who participated in a task that facilitated their ability to engage with objects via Velcro mittens later interpreted adults' reaches for the same objects as goal-directed, whereas infants without this action experience did not.

Thus, it is clear that infants' perceptual and cognitive development is influenced by their ability to interact causally with their environment. What remain unclear are the precise mechanisms mediating this relationship (see Rakison & Woodward, 2008). Several hypotheses have been put forward, including (1) that new attentional strategies are learned through motor action, changing the kind of information that infants encode (Campos et al., 2000; Cicchino & Rakison, 2008), (2) that proprioceptive input from infants' own actions is an important additional source of perceptual information (Meltzoff & Brookes, 2008; Sommerville et al., 2005), and (3) that causal action experience activates neural systems that represent both the infant's own actions as well as observed actions, allowing infants to generalize from their own experiences to those of others (Bertenthal & Longo, 2007; Decety & Grezes, 1999).

The experiments reported in this paper were designed to explore some of these proposed mechanisms in relation to infants' early causal perception following causal action experience via Velcro mittens. Specifically, do infants learn something broadly about causality from their action experience, regardless of the particular objects

involved? Rakison (2009) found that infants as young as 4½ month of age who engaged in causal actions on green balls via red Velcro mittens – but not those in the smooth mitten condition – responded to the causality of Michotte-like habituation events employing red balls that collide with green balls. However, it is not clear that infants acquired knowledge about the abstract concept of causality from this action task. Cohen and Oakes (1993) demonstrated that 10-month-old infants do not perceive causality as an abstract property of Michotte-like events but rather as a concrete property associated with the specific agent, but not the recipient, involved in the events. Thus, it is possible that infants in Rakison's (2009) study simply learned about the perceptual features of, and the relationship between, the specific mittens and balls they interacted with during the action task of the experiment. Evidence of causal understanding may then have resulted from the perceptual similarity between the objects in the habituation events and the mittens and balls encountered during the action experience phase of Rakison's experiment.

Experiment 1 addressed this possibility. Four and a half-month-old infants were given action experience similar to that used by Rakison (2009), except that the color of the Velcro mittens (blue in the present study) and the shape and color of the toys (yellow cubes in the present study) were altered. The habituation events were identical to those used by Rakison (2009) with red and green balls. If infants learn about the abstract concept of causality from their action experience, the features of the particular objects used in the action task of the experiment should not constrain infants' perception of causality during the habituation events. Thus, I predicted that infants will dishabituate to the causal switch event following the habituation trials, regardless of the color and shape of the objects encountered in the action experience phase of this experiment.

Experiment 2 was designed to determine the youngest age at which the mechanisms responsible for causal perception must be in place. This experiment replicated the original study Rakison (2009) performed using red Velcro mittens and green toy balls with 3-month-olds to determine whether infants at this young age are capable of causal perception following causal action experience.

Experiment 1

Method

Participants

Nineteen healthy, full-term 4½-month-old infants were recruited for participation in this study. The data from 4 infants were excluded from the final analyses because of failure to habituate (n = 1), looking more than 5 standard deviations beyond the mean (n = 2), and fussing or crying (n = 1). The final sample consisted of 14 infants (mean age 4.54 months; range = 3.81 months to 5.49 months). There were 6 males and 8 females. In all studies reported in this article, the participants were primarily Caucasian and had middle socioeconomic status. 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. Infants sat on their caregiver's lap, supported at the torso, directly in front of a table at chest level. A pair of blue mittens covered in Velcro was placed on the infants' hands. The mittens were fashioned after those used by Needham et al. (2002) and allowed infants to make contact with and pick up toy cubes through swiping or batting at them. A tray of 4 yellow cubes (each weighing approximately 0.3 ounces and having 1.4-inch sides) was then placed in front of the infant. The toy cubes were covered

in Velcro and designed to be similar in weight and size to the toy balls used by Rakison (2009). Infants were allowed to interact freely with the provided toys for 180 s. If the infants made contact with a cube, the experimenter waited 10 seconds to remove the toy from the mitten and replaced it in the tray in front of the infant to give the infant multiple opportunities to make contact with the toys. After 180 s, the tray with the cubes was removed from sight and the mittens were taken off the infant.

Habituation task. After completing the action task, infants participated in a visual habituation procedure identical to that used by Rakison (2009). Infants sat in their caregiver's lap and watched animated habituation and test events, which are illustrated in Figure 1, shown on a computer screen (size: 14 in. x 24 in; distance 24 in.) and created with Macromedia Director 8.0 for PC. Infants were habituated to a simple Michottian direct 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 stopped upon contact with a green ball located in the center of the screen. On contact, a "ding" sound was heard and the green ball immediately began moving to the right until off screen. The total length of each event was 8.0 s and the event could be repeated up to three times per trial. A blue screen that descended and ascended over a period of approximately 2 s separated individual presentations of each event.

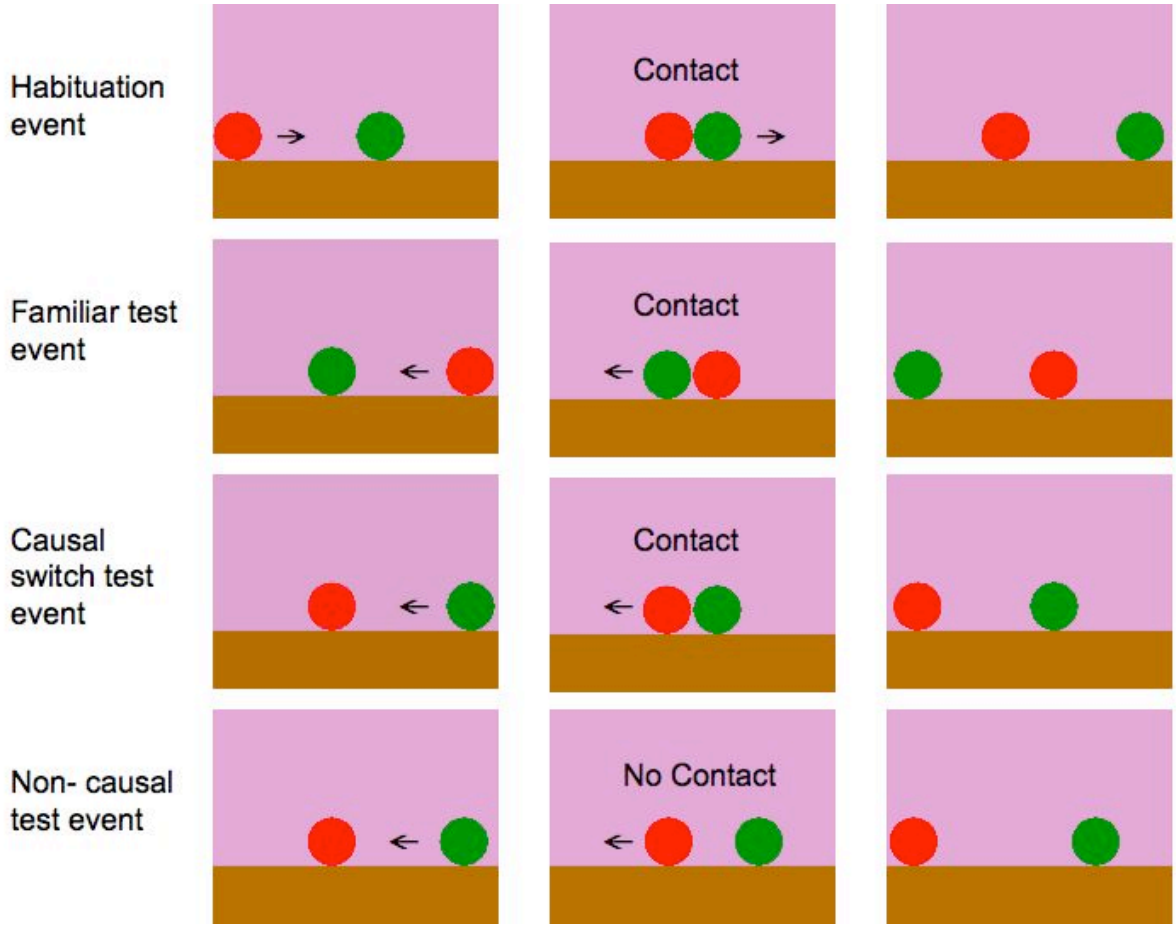

Figure 1. Habituation and test events.

After looking time to a block of three consecutive trials reduced below 50% of the total looking time of the first three trials, infants were presented with three test events, 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. The causal switch event was similar to the familiar test event but the position of the red and green balls was switched such that the green ball moved from right to left from off screen until it contacted the red ball in the middle of the screen, which then began moving to the left until off-screen. The non-causal event was similar to the causal switch event except that

the green ball stopped before contacting the red ball, which then began to move after a 1 s delay. Thus, all three test events involved a change in spatio-temporal properties (the balls moving from right to left rather than left to right), but one event preserved the causal roles of the objects from the habituation events, one event switched the causal roles from the habituation events, and one involved a change from a causal to a non-causal event. The order of the test events was counterbalanced across infants.

Procedure. Infants sat on a caregiver's lap in front of a computer screen (size: 14 in. x 24 in; distance 24 in.). An experimenter, who was hidden from the infants' view and could not see the stimuli on the computer monitor, observed the infant via a video feed from a camera placed directly behind the monitor. During the habituation and test phase, the experimenter coded the infants' looking time behavior online by pressing and releasing a preset keyboard key. Infants were presented with a green expanding and contracting circle on a black background with a synchronous bell prior to the first habituation trial and between each habituation and test trial. Each event was presented until the infant visually fixated away from the monitor for over 1 s or until 30 s of uninterrupted looking time had elapsed.

Results

The primary analyses compared infants' looking times to the three test events (familiar, causal switch, and non-causal). Preliminary analyses revealed no main effect for sex, $F(1, 4) = .108$, $p > .7$, so it was excluded from the main analyses. A repeated measures analysis of variance (ANOVA) with test event as the within subjects factor revealed no main effect of test event, $F(2, 26) = 1.15$, $p > .3$. Because longer looking times were expected for the causal switch and non-causal test events compared to the

familiar test event, one-tailed t-tests were used to compare the mean looking times to two test events relative to the familiar event. Paired samples t-tests indicated that the difference in mean looking times to the familiar test event (M = 5.26, SD = 2.50) and to the causal switch test event (M = 8.54, SD = 8.46) was marginally significant, $t(13)$ = -1.45, $p < .08$. Infants did not, however, look reliably longer at the non-causal test event (M = 6.36, SD = 6.77) than at the familiar test event (M = 5.26, SD = 2.50), $t(13)$ = -.673, $p > .2$. Infant looking times for the three test events are presented in Figure 2.

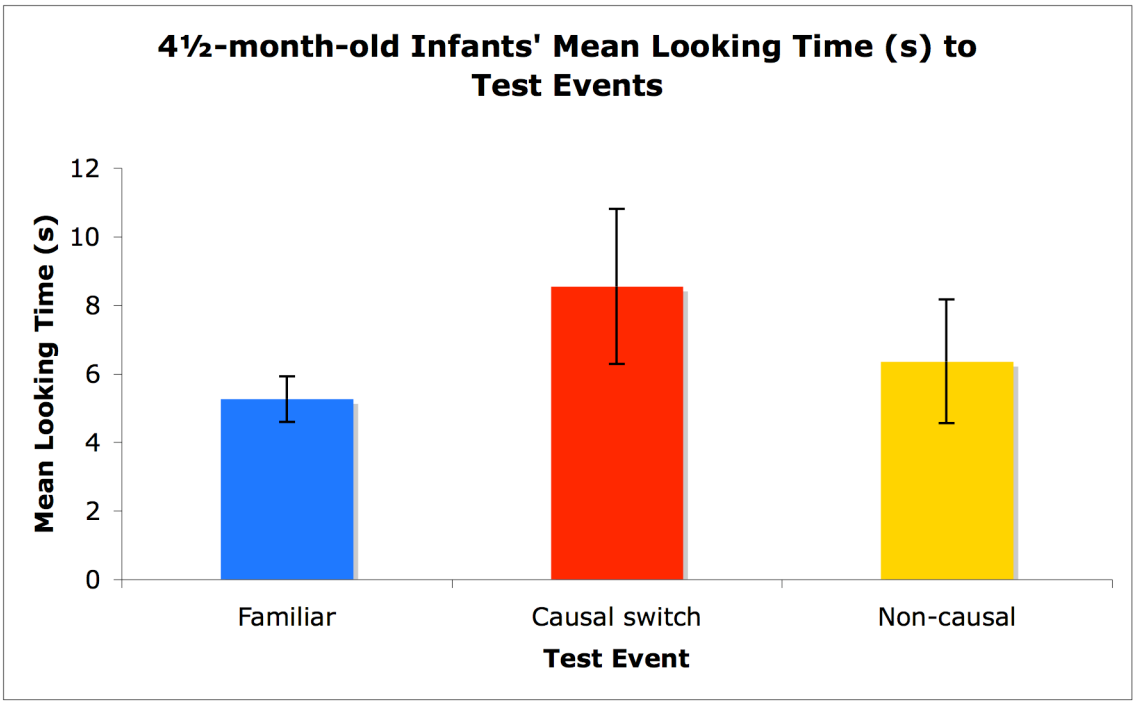

Figure 2. Mean looking time to familiar, causal switch, and non-causal test events by 4½-month-old infants following a Velcro mitten action task and habituation to a causal event.

Infants' interactions with the cubes during the action task were also analyzed to investigate possible correlations between infants' level of interaction with the stimuli and their looking times to the three test events. Four aspects of infants' interactions during the action task were coded: (1) the number of times infants touched the cubes with their mittens, (2) the amount of time infants had cubes attached to their mittens, and infants'

time looking at the cubes when a cube was (3) and was not (4) attached to their mittens. A significant positive correlation (r = .573) was observed between the amount of time infants looked at the cubes when a cube was attached to their mittens, and infants' looking times to the familiar test trial, p(two-tailed) = .032.

Discussion

The current experiment investigated a phenomenon first reported by Rakison (2009), that agentive experience facilitates infants' ability to perceive causality in simple events prior to 6 months of age. Rakison (2009) provided strong evidence that 4½-month-old infants who interact with objects via Velcro mittens responded to simple launching events in terms of causality. Following habituation to a direct launching event involving red and green balls, infants that had used red Velcro mittens to interact with green Velcro balls looked significantly longer at a test event that switched the agent-recipient roles of the red and green objects as well as to a non-causal event. Four-and-a-half-month-olds that did not interact with objects via Velcro mittens, however, increased looking time only to the test event without continuous movement.

Rakison's (2009) study did not address the mechanisms by which infants' action experience facilitated their ability to perceive causality. One possibility is that the perceptual similarity between the objects in the habituation and test events, and the mittens and balls encountered during the action task of the experiment, was necessary for perceiving causality in the test events. The current study was designed to test this possibility. In this experiment, infants' ability to perceive causality was assessed following agentive experience with stimuli (yellow toy cubes and blue Velcro mittens) that were perceptually very different from the red and green animated balls involved in

the habituation and test events. After habituation to a direct launching event, infants looked longer to an event in which the agent-recipient relation changed relative to a familiar causal event. This provides further evidence that 4½-month-old infants abstract information about causality from their self-produced actions, and that the particular objects infants interact with do not constrain their perception of causality in the test events.

Experiment 2

Experiment 2 was designed to determine the youngest age at which the mechanisms responsible for causal perception must be in place and whether infants at 3 months of age are capable of causal perception following causal action experience.

Method

Participants

Twelve healthy, full-term 3-month-old infants were recruited for participation in this study. The data from 5 infants were excluded from the final analyses because of experimenter error (n = 1), fussiness or crying (n = 3), and failure to habituate (n = 1). The final sample consisted of 7 infants (mean age 3.20 months; range = 2.79 to 3.48 months). There were 2 males and 5 females.

Procedures and Stimuli

Action task. The action task was identical to that in Experiment 1 except that infants wore red mittens and were presented with a tray of green balls.

Habituation task and procedure. The habituation task and procedure were identical to those in Experiment 1.

Results

As in Experiment 1, the primary analyses compared infants' looking times to the three test events (familiar, causal switch, and non-causal). Preliminary analyses revealed no main effect for sex, $F(1, 5) = .594, p > .4$, so it was excluded from the main analyses. A repeated measures ANOVA with test event as the within subjects factor revealed no main effect of test event, $F(2, 12) = .786, p > .4$. Because longer looking times were expected for the causal switch and non-causal test events compared to the familiar test event, one-tailed t-tests were used to compare the mean looking times to two test events relative to the familiar event. Paired samples one-tailed t-tests indicated that infants' looking times to the causal switch test event ($M = 7.13$, $SD = 4.80$) and to the familiar test event ($M = 11.30$, $SD = 12.00$), were not significantly different $t(6) = 1.11, p > .1$. Similarly, infants looked equally long at the non-causal test event ($M = 11.39$, $SD = 9.95$) and the familiar test event ($M = 11.30$, $SD = 12.00$), $t(6) = -.023, p > .4$. Infant looking times for the three test events are presented in Figure 3.

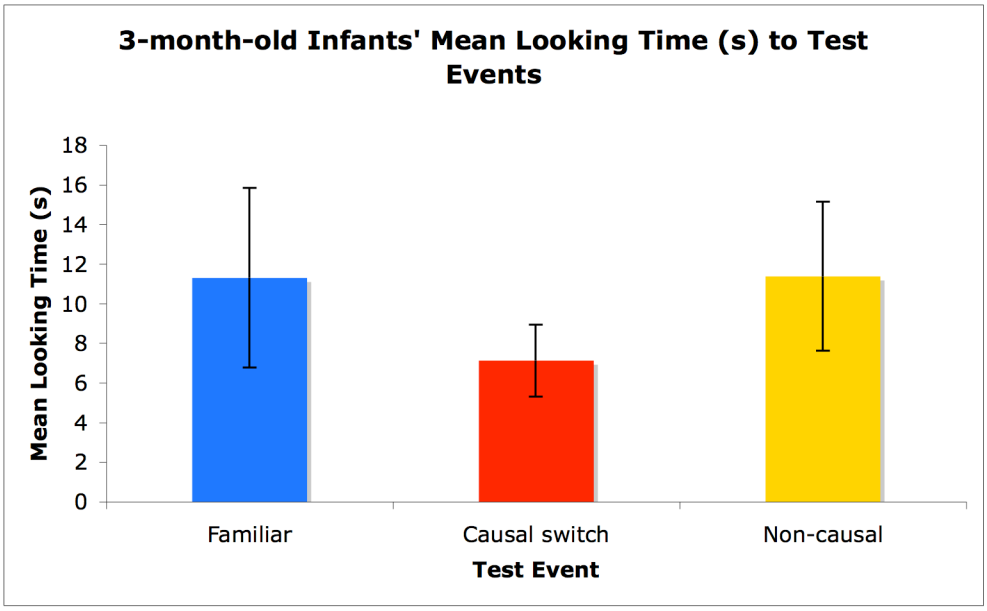

Figure 3. Mean looking time to familiar, causal switch, and non-causal test events by 3-month-old infants following a Velcro mitten action task and habituation to a causal event.

Infants' interactions with the balls during the action task were analyzed in the same manner as were interactions with the cubes in Experiment 1. A significant positive correlation (r = .895) was found between the amount of time infants looked at the balls when a ball was attached to their mittens and infants' looking time to the non-causal test trial, p(two-tailed) = .016.

Discussion

Rakison's (2009) study demonstrated that infants are capable of perceiving causality in Michotte-like launching events before the age of 6 months if first given the opportunity to interact with objects via Velcro mittens. This experiment demonstrated that this effect does not extend to infants at 3 months of age. In contrast to the 4½-month-old infants in Rakison's (2009) study, the 3-month-olds in this experiment did not look significantly longer at an event that changed the agent-recipient relation compared to a familiar test event. This experiment also provides evidence that 3-month-old infants do not respond reliably to simple launching events in terms of their continuity. Had infants perceived the continuity of the launching events, they should have shown greater recovery of attention to the discontinuous non-causal test trials compared to the continuous test trials following habituation to a continuous event, which they did not.

General Discussion

The current experiments help to elucidate both the time course of the development of causal perception in infancy as well as the role that agentive experience plays in facilitating infants' ability to perceive causality in simple events. The results of these studies also have theoretical implications in regards to the development of causal perception during infancy as well as the mechanisms mediating the relationship between

self-produced action and cognitive and perceptual development.

Little research on causal perception has included data from infants younger than 4 months of age. The results of the current studies suggest that 3-month-old infants automatically perceive neither the causality nor the continuity of launching events. This is evidence against Leslie's (1995, Leslie & Keeble, 1987) theory that causal perception is due to an innate perceptual module. If, as Leslie suggested, this module is functional from early infancy, 3-month-olds should have automatically perceived the causality of launching events, which they did not. Instead, the results lend further support of the theory that infants' ability to perceive causality develops during the first year of life (Cohen & Oakes, 1993; Oakes & Cohen, 1990; Rakison, 2009), as well as add another step to the developmental progression described by Cohen and Amsel (1998).

Cohen and Amsel (1998) demonstrated that 4-month-old infants are capable of responding to Michotte-like events on the basis on continuity of movement. There are several reasons why 3-month-old infants in the current experiment did not also respond to launching events on the basis of continuity. First, the perceptual and cognitive systems of 3-month-olds are less developed than those of 4-month-olds. Previous research by Cohen and Younger (1984; Younger & Cohen, 1986) demonstrated that whereas older infants process a stimulus as a whole and respond to changes in the relationship between features of the stimulus, younger infants process the same stimulus as a collection of independent features and do not respond to changes in relationships between those features. Thus, whereas 4½-month-old infants may have been capable of processing a simple launching event as a whole and responded to changes in the submovements of the event, 3-month-

olds may have processed the submovements independently and may not have responded to the spatial and temporal relations between the submovements.

Second, past research has also shown that infants attend more to the features of visual stimuli that they can see clearly or follow more easily compared to more difficult to process features (see Cohen, 1991). Because 3-month-old infants may have difficulty processing the submovements and continuity of a launching event, they may attend more to overall direction of movement, which is easier to perceive. Thus, 3-month-olds may have looked equally long at the three test trials regardless of differences in continuity of movements because all three events involved a change in direction compared to the habituation event.

If 3-month-olds do not respond to the continuity of launching events as much as to other features of the events that are more easily perceived, it follows that making continuity of movement more easy to detect should result in longer looking time to the discontinuous non-causal event, following habituation to a continuous event. This is what appears to have happened during the action task of the experiment. Infants that looked longer at the balls when a ball was attached to their mitten were significantly more likely to look longer at the non-causal test trial compared to other infants. Infants observed mittens making contact with and sticking to a ball, then moving continuously together with the ball before the two separated. Increased attention to such continuous events likely trained infants to better attend to continuity of movement, as well as to better detect the relation between the objects involved in causal events. Increased exposure to such training likely allowed infants to perceive the discontinuity of the non-causal test trial more easily, resulting in longer looking times to the non-causal test event

compared to infants with shorter looking times to the balls when on the mittens during the action task.

Thus, these studies contribute to a growing body of research regarding the causal relation between infants' self-produced actions and their perceptual and cognitive development. In addition to providing evidence that 3-month-old infants' self-produced actions influence their ability to respond to events as continuous, these experiments also demonstrate that 4½-month-old infants' action experience affects their ability to perceive causality. Importantly, these studies are among the first to provide evidence regarding the possible mechanisms mediating this relationship. Specifically, the effect of self-produced action on perception does not appear to be contingent on perceptual similarity between the stimuli involved in infants' actions and in the experiments used to test for causal perception. Following agentive experience with stimuli that were perceptually very different from the stimuli in the habituation and test events, 4½-month-old infants showed evidence of causal perception by increased visual fixation to a test event in which the agent-recipient relation changed relative to a familiar causal event.

Unexpectedly, no significant differences were observed between infants' looking times to the familiar and non-causal test events in this experiment. Previous research has demonstrated that even when 4-month-old infants are not yet capable of responding to Michotte-like launching events in terms of causality, they respond to changes in the continuity of the events (Cohen & Amsel, 1998; Rakison, 2009). Thus, infants were expected to look significantly longer to the non-causal test event compared to the familiar test event, regardless of whether or not they perceived the causality of the events.

This result may be explained by taking into consideration the significant positive correlation between the amount of time infants looked at the cubes when a cube was attached to their mittens, and infants' looking times to the familiar test trial. The key to understanding this correlation is that the familiar test event was a reversal of the habituation event. As such, the familiar test event was similar to the habituation event in terms of causality, but it was novel in terms of the direction of movement. Infants that looked longer at the cubes when they were on the infant's mitten may have learned new attentional strategies from their interactions that allowed them to better encode the spatial features of the habituation and test events. Research has shown that infants are typically capable responding to simple launching events on the basis of spatial features by 5½ months of age (Cohen & Amsel, 1998). Following habituation to a direct launching event, infants that in this study who better detected the directionality of the event would have shown greater recovery of attention to the familiar (reversal) event compared to other infants. This increased looking time to the familiar event may have masked the degree to which infants recovered attention to the non-causal test trial, resulting in non-significant differences in looking times to the two events.

Similarly, it is possible that infants that were better able to encode the internal structure of launching events were more likely to look longer both at the cubes when on their mittens and at the familiar test trial. Leslie (1984) demonstrated that following habituation to a direct launching event, infants that better detected the submovements of events showed greater recovery of attention to the reversal of the event. Thus, heightened attention to the spatial features or to the internal structure of the habituation and test events following the action task may have resulted in infants' increased visual fixation to

the reversal of the habituation event (the familiar test trial), masking the difference in infants' recovery of attention to the other test trials.

Thus, several factors may be responsible for the correlation between infants' level of interaction with the stimuli and their looking times to the test events. More research is needed to identify these factors as well as the possible mechanisms underlying the relationship between infants' self-produced actions and their perceptual and cognitive development. The current experiments provide evidence that infants acquire information about the abstract concept of causality from their agentive experience, regardless of the particular objects infants interact with. Additionally, these studies support the hypothesis that new attentional strategies may be learned through motor action, changing the kind of information that infants encode (Campos et al., 2000; Cicchino & Rakison, 2008).

Further research is needed to assess the veracity of other proposed mechanisms; specifically, that the proprioceptive input infants receive from self-produced action is important (Meltzoff & Brookes, 2008; Sommerville et al., 2005), and that a neural action production-observation matching system allows infants to generalize from their own experiences to those of others (Bertenthal & Longo, 2007; Decety & Grezes, 1999). Identifying the mechanism(s) by which action experience affects cognitive and perceptual development is necessary for a more complete understanding of the manner in which multimodal information contributes to learning, as well as the role that infants' physical interaction with the environment plays in their own development.

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