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Emerging perception of causality in action-and-reaction sequences from 4 to 6 months of age: Is it domain-specific?

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ABSTRACT

Two experiments (*N* = 136) studied how 4- to 6-month-olds perceive a simple schematic event, seen as goal-directed action and reaction from 3 years of age. In our causal reaction event, a red square moved toward a blue square, stopping prior to contact. Blue began to move away before red stopped, so that both briefly moved simultaneously at a distance. Primarily, our study sought to determine from what age infants see the causal structure of this reaction event. In addition, we looked at whether this causal percept depends on an animate style of motion and whether it correlates with tasks assessing goal perception and goal-directed action. Infants saw either causal reactions or noncausal delayed control events in which blue started some time after red stopped. These events involved squares that moved either rigidly or nonrigidly in an apparently animate manner. After habituation to one of the four events, infants were tested on reversal of the habituation event. Spatiotemporal features reversed for all events, but causal roles changed only in reversed reactions. The 6-month-olds dishabituated significantly more to reversal of causal reaction events than to noncausal delay events, whereas younger infants reacted similarly to reversal of both. Thus, perceptual causality for reaction events emerges by 6 months of age, a younger age than previously reported but, crucially, the same age at which perceptual causality for launch events has emerged in prior research. On our second question, animate/inanimate motion had no effect at any age, nor did significant correlations emerge with our additional tasks assessing goal perception or goal-directed object retrieval. Available evidence, here and elsewhere, is as compatible with a view that infants initially see A affecting B, without differentiation

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into physical or psychological causality, as with the standard assumption of distinct physical/psychological causal perception.

Introduction

From the first year, infants know much about the distinctive causal structure of the physical and social worlds. A cornerstone of this view is that 6-month-olds perceive cause and effect in what older observers see as object A physically launching B (Leslie & Keeble, 1987; Michotte, 1946/1963). Actions in the social world, in contrast, are perceived as goal directed (Gergely & Csibra, 2003; Gredebäck & Melinder, 2010; Woodward, 1998). Such findings mirror a classic Aristotelian distinction, with work on mechanical events focusing on efficient causes and work on action perception focusing on final causes (Falcon, 2011). However, actions not only have goals but also often are or lead to reactions. Thus, efficient causes – prior conditions that are the primary source of a change – appear in both social and physical domains, with action–reaction links paralleling physical cause – effect links.

By 8 months of age, infants indeed perceive efficient cause and effect in events highly similar to launching but without contact, seen by adults as social, goal-directed action and reaction (Kanizsa & Vicario, 1968; Schlottmann & Surian, 1999; Schlottmann, Surian, & Ray, 2009). Our primary goal here was to trace the emergence of this causal percept in reaction events between 4 and 6 months of age to compare it with existing work on infant perception of launch events. Second, we explored whether infants, like older observers, see both efficient and final causality in reaction events, that is, whether these appear to be goal directed as well as causal.

Causal perception of reaction and of launch events

Kanizsa and Vicario's (1968) reaction event (Fig. 1) involves a simple action–reaction, approach–avoidance sequence, a minimal version of Heider and Simmel's (1944) classic stimulus (see Gao, Newman, & Scholl, 2009); a two-dimensional shape moves up to another shape, which moves away before the first shape reaches it, both moving simultaneously for roughly half a second (0.5 s). Adults and children from 3 years of age see the first shape chasing the second that is trying to get away, an impression amplified when the shape moves like an animal (Schlottmann, Allen, Linderoth, & Hesketh, 2002; Schlottmann, Ray, Mitchell, & Demetriou, 2006; Watts, Schlottmann, & Ray, 2007). In contrast, if a 0.5-s delay is inserted between the motions, observers perceive two independent motions rather than a reaction.[1]

Noncontact causality in Kanizsa and Vicario's (1968) reaction event parallels contact causality in Michotte's (1946/1963) classic launch event in which observers report that one shape launches the other (for a review, see Scholl & Tremoulet, 2000). Launch and reaction events are very similar, differing for 0.5 s or less, with the second shape moving on or before contact can occur. Nevertheless, the events belong to different ontological domains to observers from 3 years of age (Schlottmann et al., 2002, 2006).

Infants below talking age discriminate launch from delayed events (Leslie, 1984, Experiment 3) and from reaction events (Schlottmann et al., 2009, Experiment 3). However, discrimination studies cannot tell us whether infants react to spatiotemporal differences between events or to differences in causality; infants might discriminate smooth, continuous contact motion in launching from discontinuous delayed motion or from noncontact motion in reaction events without appreciating that these events also differ in causal structure.

Leslie and Keeble's (1987) reversal paradigm overcame this problem, establishing that infants encode more than spatiotemporal information. In that study, 6-month-olds were habituated to either

[1] Adults could, of course, construe some form of goal-directed social interaction in delayed sequences as these may exist in the real world, but neither adults nor children from 3 years of age do so for these minimal event sequences (Schlottmann et al., 2002, 2006).

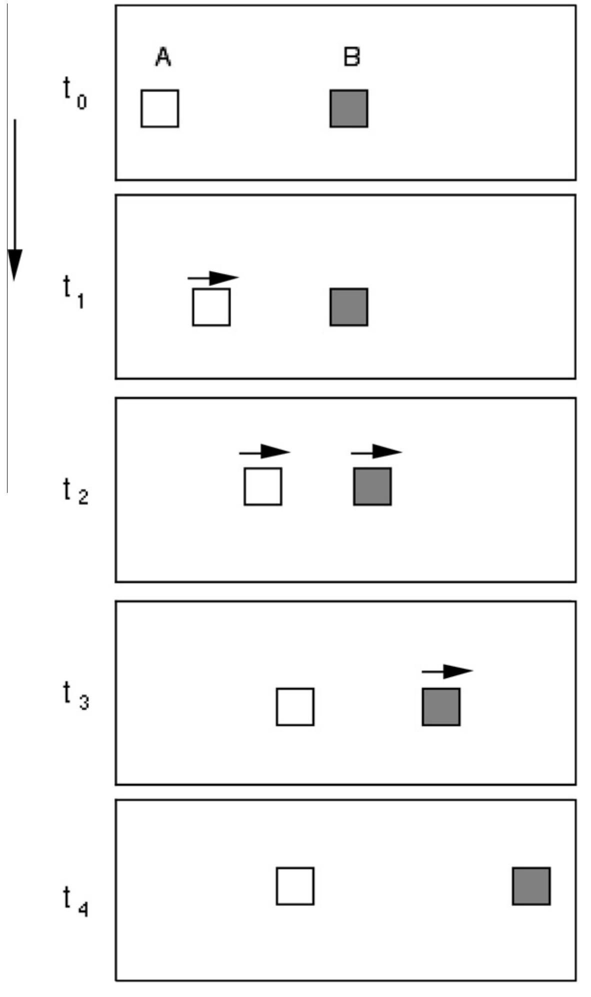

Fig. 1. Schematic causal reaction event. Shape A moves toward Shape B, which is stationary. B begins to move before contact so that both move simultaneously until A has reached its final position.

causal launch or noncausal events with a delay at the point of impact. On test, infants saw the habituation event played in reverse; that is, if the left object had previously moved first toward the right, now the right object moved first toward the left. If infants react only to spatiotemporal differences of habituation and test, then infants in causal and delay groups should dishabituate equally because spatiotemporal variables were reversed equally in both groups. Nevertheless, infants looked longer at reversed causal events than at reversed delay events. An alternative view – that infants simply react more to reversal of continuous motion than to discontinuous motion – is not plausible because 6- to 8-month-olds react very little to reversal of continuous motion per se (Leslie, 1984). Independent work with a different paradigm also confirmed that 6-month-olds are sensitive to causal, not just spatiotemporal, structure (Belanger & Desrochers, 2001; Cohen & Amsel, 1998; Oakes, 1994).

Leslie and Keeble's (1987) reversal paradigm was then also used to establish that 8- and 10-month-olds perceive the cause-effect structure of reaction events (Schlottmann & Surian, 1999; Schlottmann et al., 2009). From the same age, infants may perceive causality in more complex chase-and-escape sequences as well (Rochat, Striano, & Morgan, 2004). All in all, it is well established by now that infants are sensitive to efficient causality, not just spatiotemporal structure, in both contact and noncontact events.

To clarify, noncontact causality appears only in some noncontact events. The decisive factor is whether there is simultaneous motion at a distance, as in the causal reaction event, or merely temporally contiguous noncontact motion. The latter case indeed appears to be largely noncausal – although the distinction is less clear-cut than with temporal contiguity, with occasional causal reports in older observers (Schlottmann & Anderson, 1993; Schlottmann et al., 2006; Yela, 1952). This may be why Leslie and Keeble's (1987) focused on the clearer delayed motion control, whereas some other infant work presented averaged data from delayed contact and contiguous noncontact controls (Oakes & Cohen, 1990). An unpublished study (Redford & Cohen, 1996, cited in Cohen, Amsel, Redford, & Casasola, 1998) even reported that whereas 14-month-olds reacted more to reversal of launching events than to contiguous noncontact events, in line with the view that the latter are noncausal, 10-month-olds reacted similarly to both, so these 10-month-olds might have overgeneralized causality to the contiguous noncontact event. However, causal perception may also have been delayed because the study used complex Lego toys, not simple shapes. Oakes and Cohen (1990) and Cohen and Oakes (1993) similarly found late onset of causal perception, in contrast to subsequent work from the same laboratory differing in the substitution of simple objects for complex objects (Cohen & Amsel, 1998; Oakes, 1994). Thus, there are ambiguities in how infants and adults see contiguous noncontact events. In noncontact events with simultaneous motion at a distance, in contrast, causal perception is clear.

Regarding the developmental origin of infant causal perception, contact causality emerges between 4 and 6 months of age (Cohen & Amsel, 1998; Desrochers, 1999). Whereas 5-month-olds reacted only to the spatiotemporal features of events, 4-month-olds showed an ambiguous data pattern that may mean they mainly distinguished smooth continuous motion from discontinuous motion without detailed analysis of what features achieve continuity/discontinuity. Only 6-month-olds reacted to the causal structure of launch events.

The primary goal of our study was to collect comparable data for reaction events. Only one previous study of noncontact causality included infants under 8 months if age (Rochat et al., 2004), but this involved complex and lengthy chase-and-escape sequences with multiple changes of speed/direction, not simple reaction events, whereas cause-and-effect reversal was signaled only by a change in color of the two disks and not also by changes in direction. Thus, that only 8- to 10-month-olds in Rochat et al. (2004) study perceived causality could be due to developmental improvement in object identification (Kaldy & Leslie, 2003; Surian & Caldi, 2010) rather than improvement in causal perception.

In the current study, accordingly, we assessed whether causal perception appears for very young infants, 6 months of age (Experiment 1) or younger (Experiment 2), with simple shapes involved in simple reaction events, as shown in Fig. 1, and with reversal signaled saliently by reversal of spatiotemporal direction, as in Schlottmann and Surian (1999); see also Schlottmann et al. (2009) and Leslie and Keeble (1987). This approach provides a more sensitive test of developmental changes in reaction perception than previous work and also allows closer comparison of the developmental course of reaction causality with the existing data on launch causality (Cohen & Amsel, 1998; Leslie & Keeble, 1987).

Domain-specific versus undifferentiated causal perception during infancy

Many argue that 6-month-olds' launch perception is a perception of mechanical causality (e.g., Leslie, 1994; Saxe & Carey, 2006), as for older observers. A complementary interpretation of infant reaction perception would posit a perception of psychological causality, at minimum of goal-directed action and reaction. We refer to this view as domain-specific.[2] More conservatively, however, infants may initially have an undifferentiated "A affects B" percept of efficient cause, one that differentiates into perception of physical launching and psychological action-and-reaction later, after integration with other physical/social knowledge (Schlottmann et al., 2002, 2009). Existing studies of infant causal perception, as reviewed above, are equally compatible with both views.

[2] The controversial wider concept of domain-specific encapsulated processing is beyond the scope of this article, but see Scholl and Tremoulet (2000) and Gao et al. (2009) for discussion and relevant online data from adults.

Domain-specific causal perception was perhaps the more plausible interpretation when causal perception for mechanical launch events was first established. It fit with other work showing infant sensitivity to uniquely mechanical constraints in collisions (e.g., Kotovsky & Baillargeon, 1998; Kotovsky & Baillargeon, 2000), and nothing at the time suggested similar sophistication in infants' perception of the social world. However, the more recent findings of infants perceiving causality in nonmechanical events (e.g., Schlottmann et al., 2009) highlight similarity rather than distinctiveness of launch and reaction causality, raising the plausibility of the undifferentiated view. Thus, to distinguish the two options, we need evidence of some form of distinction between infant causal perception of launch and reaction events.

Here we looked for three types of such evidence. First, we considered, as already discussed, whether the developmental course for reaction perception is distinct from that for launch perception in previous work (Cohen & Amsel, 1998). Second, we assessed whether causal reaction perception at its point of emergence depends on animacy cues like some goal perception tasks (Woodward, 1998). Third, we explored whether causal reaction perception correlates with other measures of goal-based cognition.

Developmental paths

On the first point, divergent developmental paths for launch and reaction causality fit better with a domain-specific view than with an undifferentiated view, whereas the reverse is true for similar developmental paths. So far, the evidence suggests causal reaction perception by the end of the first year (Rochat et al., 2004; Schlottmann & Surian, 1999; Schlottmann et al., 2009), which also sees improvement in social–cognitive skills, joint attention, and social interaction (Carpenter, Nagell, & Tomasello, 1998). Causal perception of launching, in contrast, appears from 6 months of age (Belanger & Desrochers, 2001; Cohen & Amsel, 1998; Leslie & Keeble, 1987; Oakes, 1994). Thus, current results support the domain-specific view, but as argued above, a sensitive developmental test of perceived reaction causality has not yet been done.

Agent specificity

On the second point, restriction of causal reaction perception to apparently animate agents would also support a domain-specific percept. Such dependence between the nature of the agent and goal attribution occurs in the perception of simple approach action (e.g., Woodward, 1998). Similar agent specificity in reaction causality here would contrast with launch causality, which occurs with inanimate shapes.

For the 8- and 10-month-olds in Schlottmann et al. (2009), causal reaction perception did not depend on the nature of the agents, appearing equally with squares moving rigidly or in the nonrigid manner of Fig. 2, modelled on Michotte's (1946/1963) caterpillar stimulus, that appears animate to observers from 3 years of age (Congiu, Schlottmann, & Ray, 2010; Schlottmann & Ray, 2004; Schlottmann et al., 2002) and to 6-month-olds (Schlottmann & Ray, 2010). Despite animacy not influencing 8- to 10-month-olds' causal reaction perception, it is still worthwhile to reconsider this question with younger infants here; goal perception might be restricted to typical events involving animate agents at the point of emergence but generalized later (Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Legerstee, 2001). From this point of view, a link between reaction perception and agent motion might be apparent only when reaction perception first emerges. Such a finding would be a second strand of support for domain-specific causal perception during infancy; the undifferentiated view, in contrast, predicts no agent dependence early on.

Correlation with social cognition

A third approach to the issue of domain specificity is to look for correlations between reaction perception and tasks with established domain-specific social–cognitive interpretation. Thus, subsequent to causal reaction perception, we also assessed infants' goal perception and their capacity for goal-directed action.

A correlational approach is common in work on infants' ability to engage in social or goal-directed action themselves (e.g., Carpenter et al., 1998) and appears with habituation tasks in the infant intelligence literature (e.g., McCall & Carriger, 1993). A recent study also looked at correlations between

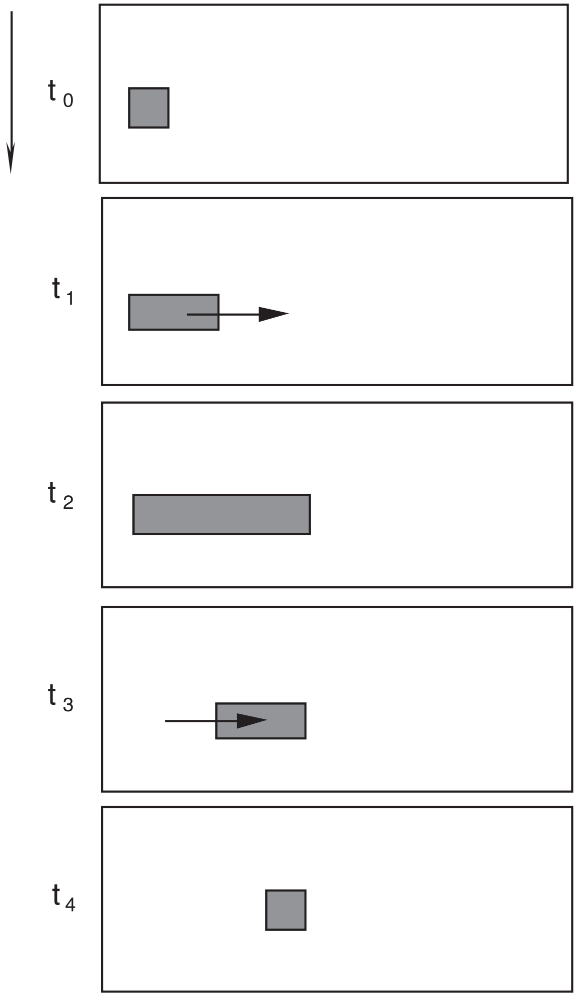

Fig. 2. Schematic nonrigid caterpillar motion. A square expands from the leading, right edge and then contracts from the trailing, left edge. The resulting translation appears to be self-generated and animal-like.

goal perception and goal-directed action (Sommerville & Woodward, 2005), but we know of no study correlating different habituation tasks to study infants' structural knowledge, so our approach is highly tentative.

To measure goal perception, we used Woodward's (1998) paradigm. Woodward habituated infants to a hand reaching for one of two toys and then switched toy location. In that study, 5- and 6-month-olds dishabituated more to reaches for the new toy in the old location than for the old toy in the new location, suggesting that they perceived a change in goals.

Mere salience interpretations of this result are ruled out because goal attribution is selective; infants do not attribute a goal if a mechanical claw replaces the hand (Woodward's, 1998) or if it is disguised by a metallic glove (Guajardo & Woodward, 2004). However, they attribute goals to inanimate objects with animate features (Luo & Baillargeon, 2005; Schlottmann & Ray, 2010; Shimizu & Johnson, 2004). Infants' goal attribution, like adults' (Heider & Simmel, 1944), requires agency cues but not naturalistic familiar agents.

Infants also do not attribute goals to any action, such as touching the toy with the back of the hand (Woodward, 1999), although this can appear to be goal directed if it pushes the toy away (Kiraly, Jovanovic, Prinz, Aschersleben, & Gergely, 2003). It takes infants 8–12 months to see pointing to/gazing at an object as goal directed (Johnson, Ok, & Luo, 2007; Luo, 2010; Sodian & Thoermer, 2004; Woodward, 2003; Woodward & Guajardo, 2002). Infants appreciate that goals depend on agents' perceptual access from 6 months of age (Luo & Baillargeon, 2007; Luo & Johnson, 2009) or on agents' beliefs from 13 to 15 months of age (Onishi & Baillargeon, 2005; Surian, Caldi, & Sperber, 2007; Surian & Geraci, 2011). Woodward's (1998) task is clearly a sensitive and robust paradigm showing that infants perceive goals widely, but only with prerequisite background understanding.

Between the two "sit still" habituation tasks – causal reaction perception and Woodward's goal perception – infants needed a break in which they could actively engage with toys/people. Willatts' (1999) goal-directed action tasks involve such interaction, allowing us to collect further data of interest without requiring much extra effort from babies. For Piaget (1936/1952), goal-directed action emerges only from 8 months of age, stage 4 of the sensorimotor period. However, Willatts (1984a, 1984b, 1999) showed that 6-month-olds search under covers or pull supporting cloths to retrieve toys with at least partial intention, and with full intention by 7 months of age, as characterized by continuous looking at the toy, by pulling the cloth and grasping the toy without extraneous exploration, and by differentiation of cloths with/without the toy. Accordingly, we expected intentional action in our 6- and 7-month-olds. Correlations between causal reaction perception and Willatts' and/or Woodward's tasks would be the third way in which the results could fit with the domain-specific view of infant causal reaction perception; the undifferentiated view predicts no correlation early on.

In sum, our aim here was to study the developmental emergence of causal perception of action and reaction and its association with social cognition. Experiment 1 assessed 6-month-olds' causal reaction perception as well as goal perception and goal-directed action skills. Experiment 2 studied 4- and 5-month-olds' causal reaction perception only.

Experiment 1

Method

Overview

All infants were first tested on causal reaction perception, then on Willatts' (1999) goal-directed action tasks, and finally on Woodward's (1998) goal perception task. Task order was dictated pragmatically: Reaction perception came first, so that fatigue would not compromise our primary results. The other tasks were ordered to maximize chances of getting infants through all tasks (discussed above). The session lasted roughly 1 h, with brief breaks between tasks.

Participants

The final sample for the causal reaction task consisted of 64 6-month-olds (31 girls and 33 boys) with no known health problems, recruited by advertisement, ranging from 181 to 216 days of age (M = 199 days). We excluded 35 further infants, 9 for fussing, parental interference, or technical problems and 26 for failure to habituate in 12 trials (15 saw causal reaction events). Of the final 64 infants, 47 and 43 took part in the search and pull components, respectively, of Willatt's (1999) goal-based action task (42 in both), and 56 participated in Woodward's (1998) goal perception task.

High exclusion rates appear frequently in infant studies. Nonhabituators were excluded here following best practice suggestions (Cohen, 2004; Oakes, 2010): nonhabituators might not have processed the habituation stimulus sufficiently to develop a novelty preference and, instead, may still have a familiarity preference that would compromise interpretation. In our design, infants with a familiarity preference would be expected to show little/no recovery on reversal, nondistinct between groups, which would wash out the predicted effects. In line with this view, nonhabituators here had very low looking times from the beginning, 13.5 s on the first habituation trial (in contrast to $\geqslant$30 s for habituators; see Results and discussion), decreasing to 8.80 s on the 12th trial, suggesting that they may well not have processed the habituation event in any detail.

Stimulus materials

Movies for the *causal reaction task* were made with MacroMedia Director. Each movie involved a red square and a blue square approximately 22 × 22 mm in size. In the left-to-right motion version, red was initially stationary on the left and blue in the middle. Red moved toward blue, stopping approximately 9 mm to its left. Blue began to move right either before red stopped, with approximately 420 ms simultaneous movement at a distance of 7.1 cm between centers in the causal reaction event, or approximately 1220 ms after red stopped in the noncausal delay event. To equate sequences with/without delay, the stationary periods at the beginning/end were adjusted, with each cycle symmetrical around the midpoint of the sequence. Right-to-left motion movies showed the left-to-right event in reverse; blue moved first from the right toward red in the middle, and then red moved. This was the only spatiotemporal difference between the two versions. Infants saw one version on habituation and the other on reversal.

One cycle took approximately 4.8 s, repeating up to 10 times, with a 750-ms interval between cycles, during which the screen went gray. In the rigid motion condition, each square moved at a constant rate of approximately 9.4 cm/s to cover a 113-mm distance in 1.2 s. The nonrigid condition corresponded to Michotte's (1963) caterpillar; the square expanded for 200 ms at approximately 18.8 cm/s to a rectangle of approximately 4.1 cm in length, with the trailing edge stationary, and then contracted, with the leading edge stationary until the original shape was recovered. These steps were repeated twice, separated by a 40-ms delay. Thus, rigid and nonrigid motion had the same average translation speed and start/end positions in both causal and delay events.

Willatts' goal-directed action tasks involved a small table, two thick black cloths, a rubber duck or a cup, and a ball. *Woodward's goal perception task* involved a blue ball with a multicolored pattern and a stuffed multicolored bird on two wooden pedestals placed on a 48 cm (width) × 36 cm (height) × 32 cm (depth) stage painted black; a screen rose from the bottom between trials. The experimenter (E) reached for the toys through a hole in the right side. Black curtains concealed the surroundings, hiding all but E's arm.

Design and procedure

Causal reaction perception task. Infants were randomly assigned to one of four groups; half saw causal reaction and half saw noncausal delay events, each with either rigid or nonrigid motion. Direction of motion was counterbalanced within these groups.

Each infant was tested in a semidark room, sitting on the caretaker's lap approximately 90 cm away from a 21-inch monitor, with other equipment hidden. The caretaker had no knowledge of the purpose/design of the study, was told not to interfere with the infant, and was instructed to close his or her eyes on reversal. A camera above the monitor recorded the infant's face, and E observed the infant on video. A Macintosh G3 PowerPC controlled the stimulus display and recorded looking times.

Trials began with beeps/colored flashes to attract attention to the screen. When the baby looked, E hit a key to start the movie and record onset of looking. When the baby looked away, E hit another key. If the baby looked away prior to the halfway point of the first cycle, the trial was abandoned; otherwise, it ended if the baby looked away for 2 s (consecutive) or after 10 cycles. Habituation continued until average looking on 3 consecutive trials fell below half of the average on the first 3 trials; the minimum number of trials was 6 and the maximum was 12. After habituation, the infant saw a familiar test (the habituation movie), followed after 30 s by the novel test (the reversal movie). The break was to ensure attention to the novel event, following Leslie and Keeble (1987). The break was used for all groups and so cannot account for group differences in recovery.

A second observer without knowledge of the purpose/design of the study checked videos for a random third of the babies; the correlation of looking times measured on- and offline was $r = .99$ for both familiar and reversal tests. When all trials—habituation and test—were considered, correlations for the 22 babies ranged from .97 to 1.

Goal-directed action tasks. Abbreviated from Willatts (1984a, 1984b, 1999), these served as filler to give infants an active break between two habituation procedures and also provided a measure of goal-based action. First, search behavior was assessed over 4 trials, on which a toy (duck or cup depending on initial interest) was hidden under one of two cloths bunched up side by side on the table to disguise the toy. The caretaker held the baby's arms to prevent search until the toy/cloths were in position; trials terminated if the infant failed to react within 30 s. On Trial 1 the toy was partially hidden, on Trials 2 and 3 it was completely hidden under Cloth A (side counterbalanced), and on Trial 4 it was hidden under Cloth B on the other side. The search trials were followed by three pull trials: The toy was placed on top of one of the cloths, which were stretched out side by side, so that the infant could reach the close end and pull the toy on the far end within reach. On Trial 1 the toy was placed on Cloth B, on Trial 2 it was placed on Cloth A, and on Trial 3 a new toy (ball) was additionally placed on Cloth B.

Scoring was adapted from Willatts (1999). E noted manual/visual behavior toward the cloth/toy on a score sheet separating four components of behavior: (a) whether and which cloth was grabbed, (b) what the infant subsequently did with it (i.e., whether the infant just held/played with it or uncovered the toy/pulled it within reach), (c) whether the infant looked at the cloth/toy, and (d) once the toy was uncovered/within reach, whether the infant picked it up or just touched it or showed no further interest. The infant received 3 points for each component if behaviors suggested clear intention directed toward the target such as immediately lifting/pulling close the cloth with the (novel) toy and picking it up. Intentional behaviors not exclusively directed at the target, such as uncovering/pulling both cloths, scored 2 points. In addition, 1 point was given where intention was ambiguous and/or directed incorrectly such as playing with the empty cloth, touching rather than grabbing the toy, and picking up the target but only after a different first action. Behaviors such as just holding a cloth without attention to the toy received no points.

Goal perception task. This followed after another short break. The procedure followed Woodward (1998) except that we used a fixed trial procedure (6 trials) and only one pair of test trials to abbreviate the session. E always reached from the right, across the stage, for the far toy on the left, with type/side of toy counterbalanced across infants; the new goal effect appears equally with reaches for the close and far toy (Woodward, 1998).

The infant sat on the caretaker's lap 50 cm from the stage. Initially, the screen lowered and, if needed, E tapped on the apparatus to attract attention. Then E's bare left arm and hand reached across the front of the stage gripping the far toy. E's hand rested at the bottom of the toy so as not to obscure the close toy and remained stationary until the baby looked away for 2 s and the screen rose. After 6 familiarization trials, the screen lowered to reveal that the toy location had been switched. On this switch trial, no hand appeared. Subsequently, the infant saw a new goal trial, during which E gripped the other toy now placed across the stage, and a new location trial, during which E gripped the old toy now placed on the close side. Test trial order was counterbalanced. A camera above the stage recorded the baby's looks, and a camera behind the baby recorded the stage action.

Looking time data were derived from videotape. An observer blind to hypotheses/design recorded looking on each trial from the moment the baby first looked at E's moving arm until the baby looked away at the end of the trial. A second observer rescored a third of the tapes. Reliability was $r = .99$ for both test trials. When habituation and test trials were considered, correlations for 18 babies ranged from .88 to 1. Video scoring revealed that in three cases, E inadvertently omitted/added a habituation trial. Because the data were unexceptional—the decrease from first to last habituation trial was similar to that for the other infants, and looking on the test trials was similar as well—they were retained in the sample.

Results and discussion

Causal reaction perception task

Habituation

Infants seeing causal reactions (referred to as the causal group hereafter) looked for 35.35 s on the first habituation trial, decreasing to 9.07 s on the last habituation trial, with 116.23 s total looking over the first 3 and last 3 trials. Infants in the delay group looked for 32.40 s on the first trial, decreasing to 7.64 s on the last trial, with 101.52 s summed looking time. The mean number of habituation trials did not differ between groups either, with 7.53 trials in the causal group and 7.22 trials in the delay group. Group × motion style × direction analyses of variance (ANOVAs) found no significant effects of these factors on either first or last trial, summed looking, or number of trials. (Three-factor independent group ANOVAs, with $df = 56$ for error, are reported throughout for different dependent variables of interest.)

As expected with habituation to criterion (Cohen, 2004), looking times recovered somewhat from last habituation to familiar test trial, $F(1,56) = 3.48$, $MSE = 5.35$, $p = .067$, $\eta_p^2 = .06$, but the decrease from first habituation trial to familiar test trial remained significant, $F(1,56) = 192.40$, $MSE = 101.95$, $p < .01$, $\eta_p^2 = .78$. There were no effects of group, motion style, or direction on either increase, decrease, or the familiar test trial itself, which had looking times of 10.05 s in the causal group and 8.18 s in the delay group. All in all, infants in the causal and delay groups showed a similar pattern of attention during habituation.

Reversal test

In Fig. 3, infants in both groups showed renewed attention when direction of motion was reversed, but infants in the causal group showed about twice as much recovery as infants in the delay group (12.74 and 6.12 s, respectively). An ANOVA on the recovery of looking from familiar test to reversal test, with group, motion style, and direction of movement as between-participants factors, found a corresponding main effect of group, $F(1,56) = 5.02$, $MSE = 139.96$, $p = .029$, $\eta_p^2 = .08$. Whether the shape moved in an apparently animate nonrigid manner had no effects, and direction also had no effects, $F(1,56) < 2.44$, $p > .124$, $\eta_p^2 < .04$.

The difference in recovery of looking between causal and delay groups was confirmed nonparametrically (Mann–Whitney $U = 323.5$, $p = .011$). When groups were analyzed separately, recovery from familiar test to reversal test was significant for both, $F(1,28) = 29.27$, $MSE = 88.77$, $p < .01$, $\eta_p^2 = .51$, $z = -5.13$, $p < .01$ (Wilcoxon) for the causal group and $F(1,28) = 11.70$, $MSE = 51.19$, $p < .01$, $\eta_p^2 = .30$, $z = -3.09$, $p < .01$ for the delay group, with no other effects. Thus, infants in both groups were sensitive to reversal of spatiotemporal direction, but the causal group was also sensitive to the reversal in causal structure.

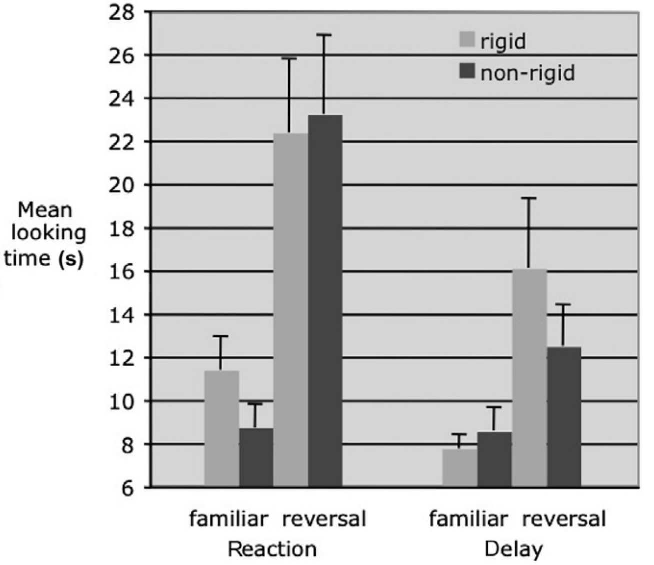

Fig. 3. Looking times and standard errors to familiar and reversal tests in causal reaction and noncausal delay groups with both rigid and nonrigid motion in Experiment 1. As can be seen, 6-month-olds recover more to reversal of the causal reaction event than to reversal of the delay event without differences depending on style of motion.

Goal-directed action tasks

We found good performance on these tasks, in line with previous work (Willatts, 1984a, 1984b, 1999). Infants mostly retrieved the toy, displaying partial or full intention, with mean scores of 8.57 (out of 12) in the search component and 9.77 in the pull component of this task. When performance on both components was compared, pulling was slightly easier than searching, $F(1,41) = 8.51$, $MSE = 2.73$, $p < .01$, $\eta_p^2 = .17$, reflecting its lower memory demand or a practice effect. For searching, there was a linear decrease across trials, $F(1,41) = 14.37$, $MSE = 12.02$, $p < .01$, $\eta_p^2 = .26$, from 10.19 on the partial hiding trial, over 9.29 and 8.36 on the A trials, to 7.48 on the B trial, where many children committed the classic AB error but then corrected themselves, as often is reported. On the pull component, children performed equally well across trials ($F < 1$). Overall performance was similar to that in previous studies (Willatts, 1984a, 1984b, 1999) without detectable fatigue in this lengthy session.

Goal perception task

Results replicated previous findings (Woodward, 1998); infants preferred to look at new goal events even at the end of this lengthy session. As Fig. 4 shows, looking time decreased over 6 familiarization trials, with some minor irregularities, from 16.26 s to 11.40 s, $F(4.18,225.44$ [Greenhouse–Geisser]$) = 4.55$, $MSE = 85.42$, $p < .01$, $\eta_p^2 = .08$, and then increased to 15.10 s on the location switch trial without movement, $F(1,54) = 7.83$, $MSE = 54.18$, $p < .01$, $\eta_p^2 = .13$. On test trials, infants clearly looked longer when the hand reached for the new goal (17.35 s) than when it reached for the new location (8.04 s), $F(1,54) = 22.67$, $MSE = 212.14$, $p < .01$, $\eta_p^2 = .30$.

Order of the test trials did not affect performance on the test trials ($F < 1$), but the group who would see the new goal test first showed less increase in looking from last familiarization to switched location trial, $F(1,54) = 4.42$, $MSE = 54.18$, $p = .04$, $\eta_p^2 = .08$. This does not qualify the main result, however, because both order groups looked longer at new goal tests than at new location tests, $F(1,26) = 13.58$, $MSE = 139.30$, $p < .01$, $\eta_p^2 = .34$, and $F(1,28) = 10.73$, $MSE = 279.79$, $p < .01$, $\eta_p^2 = .28$. This was also confirmed nonparametrically in both order groups ($z = -3.24$ and $z = -3.71$, both $ps < .01$ [Wilcoxon], respectively).

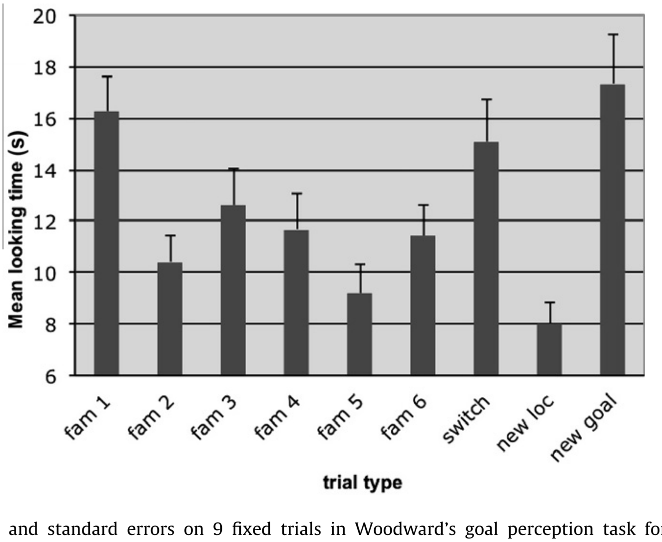

Fig. 4. Looking times and standard errors on 9 fixed trials in Woodward's goal perception task for 56 6-month-olds in Experiment 1. Infants look longer at new goal test trials than at new location test trials: fam, familiarization; loc, location.

Task correlations

Causal reaction perception (difference between looking to familiar and reversal tests) was not significantly correlated with either goal perception (difference between looking to new goal and new location events) ($r = -.22$, $p > .10$) or goal-directed action for search ($r = .05$, $p > .70$) and pull components ($r = -.20$, $p > .19$). Correlations did not improve when causal and noncausal groups were considered separately. Goal perception did not correlate with goal-directed action either ($r = -.12$, $p > .46$ and $r = .14$, $p > .39$), but goal-directed pulling and searching were correlated with each other ($r = .40$, $p < .01$). The same pattern appeared with age in days partialled out.

In summary, this experiment established that infants perceive causation at a distance in a reaction event by 6 months of age, earlier than reported previously. Causal reaction perception did not depend on the event involving nonrigid animate motion. Our 6-month-olds also perceived goal-directed action following Woodward (1998) and could engage in goal-directed action following Willatts (1984a, 1984b, 1999), but individual differences in these tasks did not correlate with individual differences in causal reaction perception.

Experiment 2

Because 6-month-olds clearly perceived causality in action-and-reaction sequences, Experiment 2 considered 4- and 5-month-olds. These younger infants were tested only on the causal reaction task.

Method

Participants

Experiment 2 included 72 infants (35 girls and 37 boys, mean age = 157 days). Of these, 48 were 5-month-olds (range = 151–183 days). A further 28 5-month-olds were excluded (6 for fussiness and 22 for failure to habituate in 12 trials). The other 24 infants were 4-month-olds (range = 126–151 days). A further 27 4-month-olds were excluded (16 for fussiness and 11 for failure to habituate in 12 trials). We had planned to test equal numbers of 4- and 5-month-olds, but it became clear that the 4-month-olds had a much higher attrition rate. Moreover, even those who made it through the experiment behaved qualitatively differently from the 6-month-olds in Experiment 1 (see Results and Discussion). Therefore, we focused on 5-month-olds, who behaved similarly to 6-month-olds.

Stimuli and procedure

The stimuli and procedure for the causal reaction task were as before. A second observer checked 24 videos (8 from 4-month-olds and 16 from 5-month-olds), otherwise randomly selected. Looking times measured on- and offline had *r*s = .97 and .99 for familiar and reversal tests at 4 months of age, respectively, and *r*s = 1 and .99 for familiar and reversal tests at 5 months of age, respectively. When all trials (habituation and test) were considered, correlations for the 24 babies ranged from .97 to 1.

Results and discussion

We report two sets of analyses: one including all 72 infants, to maximize power, and one excluding the 4-month-olds, to make sure that results did not unduly reflect their different approach (see below). Results in parentheses below are for the second analysis that included only the 5-month-olds. However, both analyses come to the same conclusion—that these very young infants, in contrast to those in Experiment 1, did not yet perceive causality here.

Habituation

The causal and delay groups behaved similarly during habituation. Infants in the causal group looked for 37.95 (37.83) s on the first habituation trial, decreasing to 7.39 (7.65) s on the last habituation trial, with 123.26 (119.54) s total looking over the first 3 and last 3 trials. Infants in the delay group looked for 32.05 (30.75) s on the first trial, decreasing to 8.35 (8.56) s on the last trial, with 104.41 (99.97) s summed

Table 1
Four-month-olds showed less systematic looking than older infants.

Experiment	Number of infants	Mean number of cancelled trials	% Infants with no, few,or many cancelled trials		
			0	1–3	>3
Habituators					
6 months (Experiment 1)	64	1.43	56	30	14
5 months (Experiment 2)	48	2.88	46	29	25
4 months (Experiment 2)	24	5.79	21	42	38
Excluded infants					
Nonhabituators					
6 months (Experiment 1)	26	4.92	19	31	50
5 months (Experiment 2)	22	5.86	41	14	45
4 months (Experiment 2)	11	7.67	45	18	36
Noncompletions (etc.)					
6 months (Experiment 1)	9	Total exclusion rate:	35% (35/99)		
5 months (Experiment 2)	6		37% (28/76)		
4 months (Experiment 2)	16		53% (27/51)		

Note. The table shows the number of infants included/excluded in Experiments 1 and 2, mean number of cancelled trials for infants who completed the experiment, % of infants with none, few, or many cancelled trials, and the overall exclusion rate at the 3 ages.

looking. Group, motion style, and direction had no effects on looking time on the first or last habituation trial or summed looking, whether the whole sample or only 5-month-olds were considered.

On the familiar test trial, infants in the causal and delay groups looked for 10.11 (10.50) and 11.94 (11.10) s, respectively, a significant increase from the last habituation trial, $F(1,64) = 15.37$, $MSE = 44.06$, $p < .01$, $\eta_p^2 = .19$ ($F(1,40) = 5.38$, $MSE = 50.50$, $p = .03$, $\eta_p^2 = .12$). Decreased looking from first habituation trial to familiar test trial remained significant, $F(1,64)$ and $F(1,40) > 141$. The decrease was smaller in the delay group than in the causal group, $F(1,64) = 5.54$, $MSE = 205.67$, $p = .02$, $\eta_p^2 = .08$, but the group difference lost significance when 4-month-olds were eliminated, $F(1,40) = 2.83$, $MSE = 180.46$, $p = .10$, $\eta_p^2 = .07$, and the decrease remained significant ($F > 57$) and to more than criterion for both groups in both analyses. A group difference also appeared in the number of habituation trials; infants seeing delay events required more trials (7.78 vs. 6.89), $F(1,64) = 4.42$, $MSE = 3.25$, $p = .04$, $\eta_p^2 = .07$. This effect again was due to the 4-month-olds. When they were eliminated, it disappeared ($F < 1$), with 7.57 and 7.16 trials in the delay and reaction groups, respectively.[3]

Also of interest is that the 4-month-olds, in line with the high attrition rate of 53%, had generally more erratic attention (Table 1). One measure of this is the number of cancelled trials, with infants looking and looking away immediately and/or E unsuccessfully trying to attract infants' attention by starting the motion. The 4-month-olds had on average 5.79 such trials, whereas older infants had less than 3. The 4-month-olds also had far more variability than older infants, with a mean standard error of 2.46 across all trials, whereas older infants had roughly half of this, and on the test trials the difference was even more pronounced. For all of these reasons, we decided not to rely unduly on the 4-month-olds' data.

Reversal test

The right panel of Fig. 5 shows recovery of 8.14 s from familiar test to reversal test for infants in the causal group and of 5.82 s for infants in the delay group when all 72 infants were considered. This group difference was not significant ($F < 1$), and there were no other significant effects. When causal

[3] On the increase from last habituation test trial to familiar test trial, there was also a Motion Style × Direction interaction, $F(1,64) = 8.69$, $MSE = 44.06$, $p < .01$, $\eta_p^2 = .12$ ($F(1,40) = 7.41$, $MSE = 50.50$, $p = .01$, $\eta_p^2 = .16$). The 5-month-olds seeing nonrigid right–left motion and the 4-month-olds seeing rigid left–right motion increased slightly more than the other counterbalancing groups, but this did not differ between the causal and delay groups and so does not qualify our main result. The same interaction appeared, for the same reason, when the decrease from first habituation test trial to the familiar test trial was considered, $F(1,64) = 3.30$, $MSE = 205.67$, $p = .07$, $\eta_p^2 = .05$, ($F(1,40) = 5.49$, $MSE = 180.46$, $p = .02$, $\eta_p^2 = .12$). This analysis also showed a main effect of direction, with infants looking longer at left–right motion than at right–left motion, $F(1,64) = 4.01$, $MSE = 188.581$, $p = .05$, $\eta_p^2 = .06$ ($F(1,40) = 2.65$, $MSE = 181.01$, $p = .11$, $\eta_p^2 = .06$), which is of little interest.

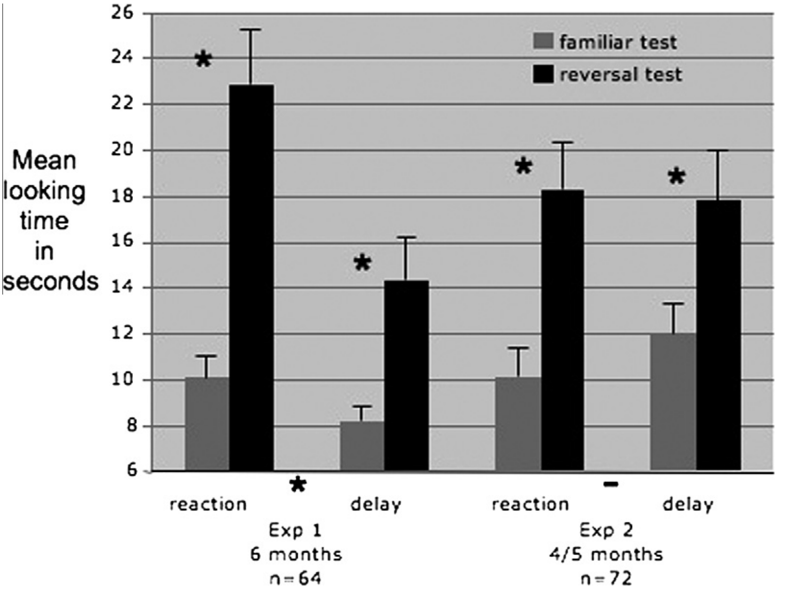

Fig. 5. Looking times and standard errors to familiar and reversal tests for Experiments 1 and 2. Asterisk (*) indicates that recovery differs significantly from 0/between groups at $p < .05$. Although 6-month-olds and younger infants recover to reversal of the habituation event, only 6-month-olds recover more to reversal of causal reaction event than to the noncausal delay event.

and noncausal groups were analyzed separately, both showed significant recovery, $F(1,32) = 14.75$, $MSE = 84.01$, $p < .01$, $\eta_p^2 = .32$, and $F(1,32) = 7.04$, $MSE = 81.63$, $p = .01$, $\eta_p^2 = .18$, respectively; there were no other effects. The result was also confirmed nonparametrically. Both groups showed recovery on reversal ($z = -2.83$ and $z = -2.81$, $p < .01$ [Wilcoxon], respectively), but the group difference in recovery was nonsignificant (Mann–Whitney $U = 597.0$, $z = -0.57$, $p = .57$).

To make sure that the absence of a group difference was not due to the erratic 4-month-olds, we redid the analyses using just 5-month-olds. We now found recoveries of 6.74 and 4.63 s in the causal and noncausal groups, respectively. The recovery within each group remained significant, $F(1,21) = 8.27$, $MSE = 70.59$, $p < .01$, $\eta_p^2 = .28$, $z = -3.03$, $p < .01$ (Wilcoxon), and $F(1,19) = 4.85$, $MSE = 47.51$, $p = .040$, $\eta_p^2 = .20$, $z = -2.16$, $p = .03$, respectively. The group difference remained nonsignificant ($F < 1$ and Mann–Whitney $U = 249.0$, $z = -0.80$, $p = .43$). This is not a matter of low power with 48 infants (compared with 64 in Experiment 1) given that the group difference remains solidly nonsignificant, $F(1,88) = 1.34$, even if a doubled sample size of 96 is assumed.[4]

In sum, infants in Experiment 2 were sensitive to the change in spatiotemporal direction like the 6-month-olds in Experiment 1, but unlike them, these younger infants did not react differentially to reversal of causal and noncausal events. This corresponds to the results with launch events (Cohen & Amsel, 1998).

Comparison of Experiments 1 and 2

We also compared recovery from familiar test to reversal test across experiments in two ways. First, we tested the 64 6-month-olds against all 72 younger infants. Second, we eliminated the erratic

[4] We literally duplicated our data set and reran the analysis for this simulated F value. Thus, the effect has the same size (our results provide an unbiased estimate), but error variability is substantially reduced. For 4-month-olds analyzed separately, recovery was 11.31 s in the causal group and 7.93 s in the delay group. This group difference was nonsignificant ($F < 1$). In fact, the recovery itself was nonsignificant as well in both groups, $F(1, 7) = 3.07$, $MSE = 149.63$, $p = .12$, $\eta_p^2 = .31$, and $F(1, 9) = 1.48$, $MSE = 139.65$, $p = .26$, $\eta_p^2 = .14$, respectively. This may reflect small sample size together with high error variability at this age. If we assume a doubled sample size, the recovery would be significant in both groups, but importantly, the crucial group difference would still have $F < 1$ even with a tripled sample size of 72.

4-month-olds. In this second analysis, the larger 6-month-old sample would dominate over the 5-month-olds; to avoid this, we included only the first 48 6-month-olds. We also removed two, three, and two outliers (box plot) from the three ages in these analyses.[5]

The crucial age × group interaction, reflecting significantly more recovery to reaction and delay events in 6-month-olds than in younger infants, reached $F(1,77) = 4.16$, $MSE = 91.15$, $p = .045$, $\eta_p^2 = .05$ when 5- and 6-month-olds were compared and $F(1,113) = 3.83$, $MSE = 106.25$, $p = .053$, $\eta_p^2 = .03$ when 6-month-olds were tested against all younger infants. The only other effects were a group main effect, $F(1,113) = 7.84$, $MSE = 106.25$, $p < .01$, $\eta_p^2 = .07$, and $F(1,77) = 5.92$, $MSE = 91.15$, $p = .017$, $\eta_p^2 = .07$, respectively, in both analyses, qualified by the interactions with age described above, and an age × direction interaction, $F(1,77) = 4.79$, $MSE = 91.15$, $p = .032$, $\eta_p^2 = .06$, reflecting more recovery in the right–left direction at 6 months of age but less at 5 months of age.

Despite low sensitivity, these age comparisons confirm the impression from the two experiments considered separately—that perceptual causality for action-and-reaction sequences manifests by 6 months of age, not before, just as previously reported for perceptual causality in collision sequences (Cohen & Amsel, 1998).

General discussion

The main finding was that 6-month-olds perceived causation at a distance in the reaction event, whereas younger infants did not. Second, sensitivity to the causal structure of reaction events did not depend on animate-like or inanimate motion pattern. Third, causal reaction perception did not correlate with goal perception or goal-directed action even though at the group level infants succeeded in both Woodward's (1998) goal perception task and Willatts' (1999) goal-directed action tasks. We now discuss how these findings fit with views on the developmental emergence of causal perception and on whether infants perceive undifferentiated causality or psychological action and reaction.

Emergence of perceptual causality for reaction events

Our finding that reaction causality emerges at 6 months is an earlier age than previously found with reaction sequences. This reflects our more sensitive procedure, with simpler shorter events and more salient causal reversal than in Rochat et al. (2004).

Younger infants of 5 months reacted to spatiotemporal structure but did not note reversal of causality over and beyond this, and it is not entirely clear that 4-month-olds even perceived the spatiotemporal reversal. To be sure, our task was demanding at 4 months, and we might find significant dishabituation to reversal of both causal and delayed events if stimuli or sample were larger (see footnote 4); that is, 4-month-olds may well be sensitive to spatiotemporal structure. This notwithstanding, there was no sign of significantly different response to reversal of causal and delayed events in 4-month-olds or the less erratic 5-month-olds, and even a substantially larger sample would be unlikely to change this. The conclusion stands that infants younger than 6 months do not appear to perceive reaction causality.

Is it no objection that the means difference between the causal and delay groups, even if solidly nonsignificant, were in the right direction for the younger infants. Although a skill could emerge rapidly, with a test producing no effect one month and a significant effect the next month, it is perhaps more typical that skills emerge gradually and/or that some children are precocious, so that below threshold effects appear at transitional ages at the group level. The pattern here fits with this view.[6]

[5] If outliers are removed from our initial analyses as well, results do not change. In Experiment 1 the crucial group main effect for 6-month-olds goes to $F(1, 54) = 10.47$, $MSE = 110.70$, $p < .01$, $\eta_p^2 = .06$, and in Experiment 2 it remains at $F < 1$ for 5-month-olds alone and for 4- and 5-month-olds combined.

[6] Most statements about age of onset in cognitive development are based on conventional significance with conventional group sizes (with very large groups, even small mean differences inevitably become significant) in cross-sectional designs. Sample sizes of 64 and 72 in Experiments 1 and 2 here, respectively, are normal to large. For comparison, Cohen and Amsel's (1998) study had 36 infants in each experiment, and Rochat et al.'s (2004) had 51 infants in their causal group plus 14 in a noncausal control group. Leslie and Keeble (1987) had 17 participants in each causal and control group. Thus, lack of power would not seem to be a concern here.

All in all, the developmental course for reaction causality when considered with a sensitive test seems to parallel that reported for launch causality by Cohen and Amsel (1998), who argued that 4-month-olds distinguish smooth continuous motion from discontinuous motion, 5-month-olds begin to process spatiotemporal structure, but only 6-month-olds process causality (Leslie & Keeble, 1987; Oakes, 1994).

Two theoretical views exist on the emergence of this perceived causality. For Cohen and colleagues (1998), it is gradually constructed over the first half year, directly reflecting the time course found here. For Leslie (1994), it is a modular and innate ability. This is not ruled out even by clear evidence that infants do not perceive causality before 6 months of age because innate abilities may unfold on a maturational schedule. The nativist position may seem vacuous, but its argument is logical: The alternative, experience-dependent view does not account for how infants create causal structure where initially there was none, and the nativist account bypasses this difficulty with a Kantian a priori argument. Both views could be combined by assuming that experience is necessary to trigger the a priori structure.

Both positions also need to accommodate the novel finding that infants are progressing not just toward perception of contact causality but equally toward perception of noncontact causality. This brings us to our second theoretical question of whether infant perception of causality is domain-specific or undifferentiated.

Action-and-reaction or undifferentiated perception of causality?

Three sources of evidence relevant to this question were considered here, and the pattern of results was as expected under the undifferentiated view. Under this view, infants see A causally affecting B in an unspecified manner in reaction (and launch) events rather than A and B engaging in goal-directed action and reaction.

Developmental course

First, simultaneous emergence of reaction and launch causality, as found by comparison of the current and previous results, fits well with the undifferentiated account, whereas a developmental lag would be more difficult to reconcile with it given similar sensitivity to both social and physical information early on. Rochat et al.'s (2004) previous finding of reaction emerging later than launch causality favored the domain-specific account, but this result did not hold up here when reaction causality was tested with a sensitive procedure paralleling that used to originally establish causal perception of launching at 6 months of age (Leslie & Keeble, 1987).

Although the undifferentiated view is the more parsimonious interpretation of parallel developmental paths, we cannot rule out that two distinct perceptual causalities emerge at the same age: one tied to physical reasoning and one tied to social reasoning. This is not inherently implausible. Simple goal-based cognition is within 6-month-olds' grasp (Luo & Johnson, 2009; Woodward, 1998), and perceived reaction causality involves only attributions of goals and perception, not usually those of intention and internal states, even in older children and adults (Castelli, Happe, Frith, & Frith, 2000; Congiu et al., 2010; Schlottmann et al., 2006).

Agent effects

Second, that perception of causality in reaction events did not depend on the nature of the agents at any age tested here also fits better with the undifferentiated view. We found no evidence for a position that goal perception might be limited to typical events involving animate agents when it first emerges (Kamewari et al., 2005; Legerstee, 2001). Such evidence would have been incompatible with the undifferentiated view, under which the nature of the agents can only matter later after learning. Indeed, agents do affect adults' causal impressions of reaction and launch events (Schlottmann et al., 2006), in contrast to the findings for infants here and for older children (Schlottmann et al., 2002).

One might wonder whether we found no agent effects because their nature does not matter for early causal perception or because both rigid and nonrigid shapes are perceived as agents. The latter view arises from Premack's (1990) claim that self-initiated motion is a major cue to agency; our rigid shape also self-initiated motion. Empirically, however, self-initiated motion is not necessary to identify agents (Csibra, Gergely, Biró, Koos, & Brockbank, 1999), and it was not sufficient in the control conditions of numerous studies (Johnson, Slaughter, & Carey, 1998; Luo & Baillargeon, 2005; Movellan & Watson, 2002; Schlottmann & Surian, 1999; Schlottmann et al., 2009; Shimizu & Johnson, 2004). In fact, self-initiated rigid motion, as used here, does not trigger goal attribution in Woodward's (1998) paradigm, whereas our caterpillar motion does (Schlottmann & Ray, 2010). These data argue against a view that the rigid shape here also appeared as an agent.

Still, we cannot rule out the domain-specific view completely because infant goal attribution does not depend on agency cues in all events. Csibra and colleagues (Biró, Gergely, & Csibra, 2007; Csibra, 2008; Csibra et al., 1999) argued that the form of an action itself—without the need for agent cues—specifies goal directedness if the action is rational/efficient in its environment. The approach–avoidance motion of reaction events could specify goal directedness directly as well. In this view, animate agent cues are needed for infant goal attribution when the event itself is ambiguous, as in Woodward-style simple approach motion. Thus, lack of agent-specific reaction causality can be made to fit with the domain-specific view.

Correlation with other goal perception and action tasks

Third, 6-month-olds here perceived goal directedness in Woodward's (1998) paradigm and acted in a goal-directed manner in Willatts' (1999) task, in line with previous work. However, individual differences in goal processing did not correlate with individual differences in perceptual causality. This is the third way in which we failed to find positive evidence for domain specificity.

This was the most tentative aspect of our procedure, without precedent in the literature, and the lack of correlations may simply reflect dissimilar tasks with different determinants of individual differences. Infant perception and action dissociate frequently (e.g., Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Hood, Carey, & Prabanda, 2000), and to date correlations between goal-based action and goal perception appear in only one study; the frequency of 10-month-olds deliberately pulling the cloth with the toy in Willatts' (1999) task correlated with the degree of preference for new goal trials when an actor pulled the cloths (Sommerville & Woodward, 2005; see also Woodward & Guajardo, 2002). For younger infants, perception–action links have appeared at the group level, but not at the individual difference level; after "reaching" for toys with Velcro mittens, 3-month-olds showed the new goal effect when an actor with mittens reached for the toys (Sommerville, Woodward, & Needham, 2005; see also Hamlin, Hallinan, & Woodward, 2008). To reveal perception–action links, tasks may need to be closely aligned. Our search for correlations between dissimilar action and perception tasks may have been overambitious.

Lack of task similarity extends to details of procedure that differed between our two perception tasks. The causal reaction perception procedure was infant controlled, with 7 or 8 habituation trials on average; looking decreased by half for all. The goal perception task had a fixed trial procedure with 6 trials; looking decreased to 70% on average. This itself may have made it difficult to find similarities in habituation/dishabituation patterns. We used strict habituation to obtain clear evidence on perceived reaction causality at 6 months of age, our main goal, because this had never been shown before. We used a fixed trial goal perception procedure to maximize chances of obtaining test trial data late in a long session. However, parallel procedures would be preferable in the future. The use of two infant-controlled procedures in one session is practically difficult, and the use of two test sessions introduces new sources of variability, but fixed trial procedures for both tasks may be a way forward. Clearly, with improvements, the correlational approach has further potential to test the domain specificity of infant causal perception; for instance, one could consider correlations between individual differences in a causal perception task and a domain-specific expectation task, both using the same events and identical habituation procedures.

In the meantime, our result that infants, as a group, perceived goal directedness in Woodward's (1998) goal perception task and acted in a goal-directed manner in Willatts' (1999) tasks already serves to rule out yet another reason for the lack of correlations found: The current sample of 6-month-olds was clearly not simply delayed in goal-based cognition.

In sum, the current experiments could have provided evidence for domain specificity and against the undifferentiated view in three logically independent ways. No such evidence appeared. It is worthwhile to briefly consider the status of our data. None of our tasks had null results. All were highly sensitive to young infants' abilities, showing perceptual causality, goal perception, and goal-based action by 6 months of age. However, the domain-specific view made more specific predictions, and in these respects the data were uninformative. The absence of evidence is not evidence of absence, of course, and when various task-specific factors are considered the data remain compatible with the domain-specific view. Nevertheless, persistent failure to find conclusive data shifts the balance of plausibility somewhat. At a minimum, it highlights the need for more work in this area.

In the remainder of this discussion, we consider what advantage, other than parsimony, undifferentiated causal perception in infancy might have and why the wider literature on causal inference does not solve the question of domain specificity either.

Undifferentiated perceptual causality?

What makes the idea of undifferentiated perceptual causality attractive is that it applies potentially far more widely than separate reaction and launch causalities could. Whereas launch or reaction events are often treated as paradigm cases for real-world causality, many other causal sequences (beginning with a ball causing a person to yell and jump out of the way) look nothing like them. Recent interest in perceptual causality has been due in part to the recognition that perceptual causality may serve as a mechanism for learning, allowing children to automatically identify and group together causes and effects in the event stream without requiring prior knowledge or focal attention (Leslie, 1994, 1995; Schlottmann, 1999). Such a learning mechanism would be even more useful if it applied across domains to diverse and novel causal sequences, not just reaction and launch events.

Just as the interpretation of perceptual causality may be less specific than assumed by a domain-specific view, the stimulus conditions under which it is perceived might also be broader than usually acknowledged. Michotte (1963) separated perceptual causality (for motion events) from a more general perception of dependence (for changes without motion as well). But it is not clear that Michotte's categorical distinction between causality and dependence can be justified empirically, and in any event the wider category of dependence may be of more general importance. We know little about the perceptual conditions under which causality/dependence is perceived except that it is not the same as perceptual co-occurrence; despite early reports (Yela, 1952), people do not experience a strong causal illusion when viewing contiguous motion at a distance (Schlottmann et al., 2006) or some contiguous qualitative changes such as in color (Schlottmann & Shanks, 1992; Young & Falmier, 2008). Contrary to Michotte (1963), causality/dependence perception is not limited to the perception of visual motion either, and causal illusions occur without it (e.g., Duncker, 1945; Huber, Schlottmann, & Daum, 2004; Schlottmann, 1999). The paradigm cases of launch/reaction events are well known, but boundary conditions for causality/dependence illusions remain to be established. The point here is that broader conditions for perception of causality/dependence and a less restrictive undifferentiated interpretation might support children's causal learning more widely than strictly domain-specific percepts.

Of course, even if infants do not have our domain-specific percepts, there are other possibilities for what they may see than the undifferentiated view proposed here. There is lengthy discussion of this issue in Schlottmann and colleagues (2009) considering, for instance, why perception of physical causality and domain-general Bayesian causal learning (e.g., Gopnik et al., 2004; Sloman, 2005) are not plausible accounts of infant perceptual causality. In the end, our undifferentiated view differs only minimally from standard domain-specific views, assuming a single perceptual template that does not belong to physical or social domains but applies to either instead of separate templates for launch, reaction, and potentially other causal events, as assumed for older observers (e.g., Schlottmann, 2001; Scholl & Tremoulet, 2000). Infants' finer-grained spatiotemporal distinctions among launch, reaction, and related events (Leslie, 1984; Schlottmann et al., 2009) might not be part of this early causal representation. Domain-specific launch/reaction percepts by 3 years of age (Schlottmann et al., 2002) could result from infants integrating early knowledge of the spatiotemporal structure of the physical and social worlds with this perceptual causality template.

Note that the undifferentiated view of infant perceptual causality does not imply a domain-general view of infant cognition; it merely argues that some early causal representations are not yet embedded with infants' domain-specific knowledge. In fact, to return to the initial distinction between Aristotle's efficient and final causality, only the former is treated as undifferentiated here. Multiple conceptualizations of causality have existed for millennia, and philosophers still have not converged on a single concept. Multiple principles of causality, some domain specific and some not, may already appear in infant cognition.

What does "causal understanding" really mean?

The domain-specific view of perceptual causality is popular because it fits with other studies of infants' understanding of the social and physical worlds, often summarized as showing a causal understanding. However, this phrase has two meanings. It may mean that infants respond in differentiated ways to causal structures in the environment or that infants represent such structures as causal. The important point is that the former does not imply the latter. Differentiated responses to relationships between observed variables unique to particular physical or social systems imply sensitivity to the underlying domain-specific mechanisms that generated them. But infants need not represent these relations as causal; associative knowledge can explain such data equally well.

The importance of causal perception tasks is that positive responses here indicate more than associative knowledge, with infants appreciating that cause and effect have different roles, with one ultimately producing the other. However, many studies taken to show infants' domain-specific causal perception in Saxe and Carey (2006) involve no empirical measures of perceptual causality. The studies show domain-specific knowledge but are ambiguous with respect to causal perception. The legitimacy of assuming causal perception, then, depends on how similar experimental events are to standard perceptual causality displays; our studies and others (Cohen et al., 1998; Leslie & Keeble, 1987) all show that even minor changes destroy perceptual causality for infants as for adults (Michotte, 1963). It is problematic, then, that many studies cited in Saxe and Carey (2006) did not involve launch/reaction variations at all or involved events that occurred in part out of sight.

Extrapolation from causal perception to inference tasks in which part of the event is hidden could be appropriate if tasks differ mainly in inferential demand. On this view, inference tasks are harder but not qualitatively different, with even causal perception requiring an inference of the connection between cause and effect. This, however, goes against Michotte's (1963) argument that causal perception is in essence a form of Gestalt perception, not inference proper. Moreover, if tasks are similar and only graded in difficulty, we would expect greater sensitivity overall in the easier causal perception paradigm; it should be more sensitive not only to causal structure but also to domain-specific structure. The data are contrary to this expectation; causal perception tasks provide evidence for causal representation but not domain specificity, and causal inference tasks show the opposite.

To illustrate the difficulty with inference tasks, consider findings that infants, seeing a beanbag flying onto the stage from left/right, are surprised when an inert object appears on that side but not when an agent appears on that side (Saxe & Carey, 2006; Saxe, Tenenbaum, & Carey, 2005). Here conditions are far from those for perceptual causality; only cause or effect is shown, never a complete cause–effect sequence. The data show sensitivity to the structure of action but not that infants represent this as causal, with the same result predicted if infants merely associate typical agents and actions.

Statistical knowledge of agents associated with (non)contact motion could also account for results obtained with Ball's (1973) paradigm (see Newman, Choi, Wynn, & Scholl, 2008), which presents what to adults appears like a collision, with contact between the objects hidden behind a screen. Perceptual causality is more likely in this paradigm than in the one described above because incomplete launch events may be amodally completed in adults at least (Michotte's, 1946/1963; Kiritani, 1999). After habituation to incomplete events, infants are surprised to see launching with a gap but not to see a complete collision (Kosugi & Fujita, 2002; Spelke, Phillips, & Woodward, 1995; see also Kotovsky & Baillargeon, 2000). Infants are not surprised at either event if a human emerges from behind the screen. If perceptual causality is assumed, then this agent effect might mean that the causal percept is domain specific or that launch perception is simply disrupted by irregular human motion, as appears for adults (Schlottmann et al., 2006), so the data are not clear.

Kotovsky and Baillargeon's (1994, 1998) studies on infants' understanding of size–distance relations in launch events are stronger, not requiring assumptions of amodal completion. A large or small object launched a target to the end of the track, much farther than during habituation with an object of intermediate size. The 6-month-olds looked longer at the less plausible small object test event than at the large object test event. This directly shows that infants see size and distance as related in a collision. Indirectly, it shows sensitivity to conservation of momentum because size reflects mass. Again, this study does not measure perceptual causality, and associative knowledge of what type of object and motion tend to go together predicts the same responses, but during habituation infants saw repeated launch events, exactly as in a causal perception study. The ensuing representation can evidently be interrogated just as easily regarding size–distance relations as regarding cause–effect roles. Thus, a purely associative view would seem to be too conservative here.

The question of whether the causal percept in Kotovsky and Baillargeon's (1994, 1998) studies is domain specific awaits demonstration, however, that perceived reaction causality is not sensitive to size–distance relations. Of course, the principle of momentum does not apply in the social domain, but an expectation that agents run farther from larger predators fits with intuition; related intuitions have already appeared in older children (Wilkening, 1981) and infants (Thomsen, Frankenhuis, Ingold-Smith, & Carey, 2011). Thus, Kotovsky and Baillargeon's (1994, 1998) paradigm might not provide a clear answer either.

Finally, Wang, Kaufman, and Baillargeon (2003) proposed teaching experiments to separate associative/statistical knowledge of collisions from causal knowledge. If infants learn only observed statistical relationships, then after suitable observations they should find it just as easy to learn true physical relationships rather than non-normative relationships. If incorrect relationships prove to be difficult, it would indicate prestructured knowledge. This could disentangle the different levels at which infants might represent causal structure. Infants have difficulties with non-normative learning about covering events (Wang & Baillargeon, 2008), but no data have appeared on collision or action–reaction sequences.

In sum, some argue that there is already good evidence that infants have a domain-specific causal understanding of their world, so that ambiguity in causal perception paradigms could be resolved by reference to this wider literature (Carey, 2009; Saxe & Carey, 2006). However, inference studies show infant sensitivity to domain-specific structures, not that infants represent these structures as causal, whereas causal perception studies have not found evidence for domain specificity. Existing data are all compatible with the undifferentiated view.

Conclusion

The current study shows that perceptual causality for reaction events emerges by 6 months of age, in parallel with perceptual causality for launch events. In contrast, 5-month-olds are sensitive only to spatiotemporal motion features, again in parallel with launch events. The developmental pattern is striking, but the question of whether perception of reaction causality is domain specific from its point of emergence remains unresolved. As argued above, this open issue looms equally over infant perception of launch causality: There are currently no data showing that this is domain specific either, so further studies are urgently needed.

Since Premack (1990), Leslie (1994), and Mandler (1992), many assume that a basic principle by which infants separate the social and physical worlds is whether an object interacts by contact or at a distance. If infant perception of efficient cause is initially undifferentiated, this assumption would need to be reconsidered even within generally domain-specific views of infant cognition. We hope that the current study helps to raise awareness of this issue.

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