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Eight-Month-Old Infants Infer Unfulfilled Goals, Despite Ambiguous Physical Evidence

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In this study, we tested whether 8-month-old infants could infer an actor's unfulfilled goal, despite some physical information present in the displays being inconsistent with the attempted goal. Infants saw a human hand holding a ring repeatedly approach the top of a plastic cone in an apparent failed attempt to place the ring on the cone. The hand and ring then bounced away from the top of the cone toward the floor. Thus, some information presented was relevant to the goal (the motion toward the goal, the afforded relationship between the ring and the cone, and the repeated attempt), but some of it was irrelevant to the goal (the movement away from the goal). Infants were presented with 2 test events: 1 that was consistent with all the trajectory information but inconsistent with the goal, and 1 that was consistent with the goal. Eight-month-olds looked longer to the trajectory-consistent event, suggesting they were able to infer the goal despite the physical ambiguity. Infants who had not been habituated to the failed attempt or who saw a matched inanimate control did not show this pattern, suggesting that infants in the first year of life actively and selectively analyze the unfulfilled goal-directed behavior of others.

Understanding that underlying mental states motivate others' actions is an integral aspect of correctly interpreting the social world. By interpreting others' behaviors in terms of their intentional, rather than simply their physical, nature, we are able to use external behavior as evidence of others' internal desires and motivations, and even to evaluate underlying personality traits. An important aspect of this pro-

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cess is that to fully understand the link between outward behavior and inward intention, one must understand that this link is not always perfect. Indeed, when viewing someone act in the world, there are often situations in which one's physical behaviors are inconsistent with his or her goal—such as in cases where a desired physical end state is unattained (e.g., when someone is unable to reach an object), or when an action brings about undesired physical effects (when someone accidentally knocks something over). In these cases, reasoning about someone's intentions based solely on action outcomes would lead to incorrect conclusions. Adults rarely make this mistake; however, correctly interpreting unfulfilled goals is not necessarily trivial to a developing infant. Because unfulfilled goals require that an observer ignore perhaps irrelevant physical information to determine the intention behind an action, infants' interpretations of such events are particularly important in exploring their intentional understandings.

When do infants come to understand unfulfilled goals? Several studies have examined infants' ability to infer the intentions of others in cases where goal information is misleading, or simply unavailable—as when an actor fails to achieve a goal (Bellagamba & Tomasello, 1999; Carpenter, Akhtar, & Tomasello, 1998; Hamlin, Hallinan, & Woodward, 2008; Johnson, Booth, & O'Hearn, 2001; Meltzoff, 1995), makes a mistake (Carpenter et al., 1998), or when the outcome of an action is hidden (Csibra, Biro, Koos, & Gergely, 2003; Wagner & Carey, 2005). Although there is agreement that by sometime in the second year of life infants can correctly interpret cases of unfulfilled or unseen goals, many studies have found failures in younger infants—suggesting a developmental trajectory in success on these tasks (Behne, Carpenter, Call, & Tomasello, 2005; Bellagamba & Tomasello, 1999; Brandone & Wellman, 2009; Csibra et al., 2003). Despite documented developmental differences, however, recent research has shown that 7-month-old infants reproduce an actor's unfulfilled goal to reach a particular object (Hamlin et al., 2008), and 6- to 9-month-old infants show increased attention when a hand is seen grasping a toy that it was not previously reaching toward (Daum, Prinz, & Aschersleben, 2008). These successes with infants younger than 1 year of age suggest that infants might understand unfulfilled goals by the middle of the first year of life, around the same time they succeed at tests of fulfilled goal understanding (Woodward, 1998, 1999).

What can account for findings that seem to be at odds in terms of when infants understand unfulfilled goals? We suggest that the difference between studies that young infants tend to pass versus fail is relatively basic: The former have tended to represent far simpler situations of unfulfilled intentions. Indeed, studies testing infants in the first year of life have presented action sequences that stop or are occluded immediately before a goal is reached, and then tested whether infants show sensitivity to the goal they never saw occur. Thus, these studies have attempted to test whether infants are able to infer a goal by "reading immediately ahead" and continuing the physical trajectories presented in the scenes. For example, Hamlin and colleagues (2008) presented 7-month-old infants with an experimenter who stretched her hand toward one of two toys that were just out of reach. Following the presentation of this uncompleted goal, infants were asked to choose a toy for themselves. Results showed that infants tended to choose the same toy the experimenter had reached toward, suggesting that infants were sensitive to her goal despite the failed reach. Importantly, it was not the case that infants were using only the physical information present to solve this task: Infants did not choose the toy that the actor had performed an ambiguous action toward, suggesting that young infants are selective in their goal interpretations.

Given this previous work, it appears that when the end state of an action sequence is omitted due to a pause or occlusion of the events immediately before the goal is reached, infants by the end of the first year of life are nonetheless capable of reasoning ahead to infer a rational, goal-based ending, and they do so only when a goal interpretation is appropriate. This is impressive, but it is perhaps worth noting that in the real world goals do not typically go unrealized simply because they are paused or occluded just before a goal is reached. Instead, it is often the case that actions continue beyond the intended goal, and as such include information that is both relevant and irrelevant to what the actor wished to achieve. In these events, one must reason about a likely intended outcome using some, but not all, of the information provided. For example, one commonly observes a shooter in a basketball game bounce the ball off the rim of the basket, even though he or she intends to put the ball through the hoop. To correctly interpret this event as containing a goal to score a basket, an observer must realize that the first half of the event, when the shooter faces the basket, aims, and throws, is goal-relevant, and the second half, when the ball bounces off the rim and back toward the shooter or into the stands, is goal-irrelevant. This interpretation is likely aided by the fact that throwing a round object toward a round hole is likely to be the result of a desire to put the object through the hole; that is, the basketball situation affords an identification of the goal as ball-in-basket, rather than as ball-off-rim. Through a selective interpretation of all of the physical information (e.g., both trajectory and affordances) provided in these events, one is easily able to understand the intended outcome.

Situations like the preceding highlight the fact that identifying someone's goal is not necessarily trivial, and raise important questions about how we differentiate information that is goal-relevant from information that is goal-irrelevant, given conflicting inputs. Once we have determined that some behavior is likely *goal-directed* (perhaps because an animate creature is doing it; see Johnson et al., 1998, for discussion of cues to animacy) in many complex events in the world we might also need to determine what the goal actually is, based on the information present. Although in some cases a goal is obvious, as when one successfully achieves a goal or struggles for a specific object, in some cases, as in the preceding basketball example, it is not. In these latter cases, some analysis of the physical nature of intentional events is required; the observer must determine which physical information is goal-relevant and which is not. Whereas previous work into young infants' intentional action understanding has been extensive and suggests they readily interpret goals in intentional cases where all of the physical information is goal-relevant (Csibra et al., 2003; Daum et al., 2008; Hamlin et al., 2008; Wagner & Carey, 2005; Woodward, 1998, 1999), to our knowledge there has been no research to date on whether young infants can interpret others' goals in contexts in which some of the physical information is goal-irrelevant.

In the studies reported here, we ask whether 8-month-old infants are capable of distinguishing the goal-relevant from goal-irrelevant information in a common unfulfilled goal scenario, and of using only the goal-relevant aspects of the event in their interpretation of the goal of the event. That is, can infants use information selectively in their goal interpretations? We hypothesized that even when an uncompleted goal event is presented in its entirety, and when some physical trajectory information is actually inconsistent with the intended goal, infants would be motivated to conduct an analysis of the functional aspects of the display, and the afforded relationships of one object to another, to infer the intended end state.

Eight-month-old infants were habituated to an event in which an actor's hand repeatedly attempted, but failed, to place a ring on a cone from a common infant ring-stacking toy. After the hand failed to place the ring on the cone, the hand (holding the ring) moved back away from the cone toward the ground before pausing in midair. This was done to establish that the final physical trajectory of the hand did not "point" to the intended goal; in fact, it pointed away from it. Infants were shown failed attempts in a looping sequence to represent a repeated attempt to place the ring on the cone, as might occur in an unfulfilled goal scenario in the real world, and to ensure that the event was maximally physically ambiguous. At test, infants were presented with completed events that resulted in two end states: one consistent with the final physical trajectory of the hand (resulting in the ring on the ground beside the cone), and one consistent with the actor's intentions (resulting in the ring on the cone). If infants are able to infer the goal to place the ring on the cone from the ambiguous habituation sequence, then they should show increased looking when the hand places the ring on the floor next to the cone, despite its being more physically similar to the ambiguous habituation display.

Two additional groups of infants saw control events designed to ensure that any effects obtained were not simply the result of the ring/cone affordance. The hand–test only group saw only test events in which the ring was placed on or off the tower, without having first been habituated to the unfulfilled goal scenario. This condition was designed to ensure that infants' interpretation of the events was influenced by their having seen the habituation event, rather than a prior expectation that hands should put rings on cones. Additionally, a second control group saw habituation and test events that were identical to those in the hand condition, except that they were carried out by an inanimate claw. Multiple previous studies have used this contrast and have found that infants do not attribute intentions to inanimate claws, even when they behave in ways that are viewed as intentional when done by hands (Meltzoff, 1995; Woodward, 1998).[1] Therefore, in the inanimate claw condition, we predicted that despite the salient affordance relationship between the ring and the cone, in the absence of animacy information, infants should not attribute a goal to place the ring on the cone, and would not discriminate the two test events. We chose 8-month-old infants as participants because there is controversy about whether infants under 1 year of age can correctly infer unfulfilled goals. Whereas some recent studies suggest that they do (Daum et al., 2008; Hamlin et al., 2008), other studies have found null effects with younger age groups (Brandone & Wellman, 2009; Csibra et al., 2003). Thus, this study aimed to test the ability of younger infants to make inferences about others' unfulfilled goals, when the goal presented to them is physically ambiguous.

METHOD

Participants

Thirty-six full-term 8-month-old infants participated. Twelve infants (5 girls, *M* age = 8 months, 1 day; range = 7;15–8;19) participated in the hand condition, 12 infants (7 girls, *M* age = 7 months, 26 days; range = 7;16–8;7) participated in the hand–test only condition, and 12 infants (5 girls, *M* age = 8 months, 2 days; range = 7;17–8;14) participated in the claw condition,. Data from an additional 6 infants were discarded because of procedure error ($n = 4$), failure to complete study due to inattention and overall fussiness ($n = 1$), and parental interference ($n = 1$). Infants were recruited through the database maintained by the Yale University Infant Cognition Lab, and were given a token gift for their participation.

Procedure

Infants sat in a darkened room on their parent's lap, approximately 60 cm from a projection screen that was surrounded with black curtains. An additional black curtain was raised and lowered between trials to reveal and occlude the screen. On curtain raisings, a squeezed squeak toy directed infants' attention toward the screen. Parents were instructed to sit quietly with their infants, not to speak with them, and not to attempt to influence their looking in any way.

[1]Many studies have found that infants *can* apply goal-directed reasoning to nonhuman entities, when sufficient cues to animacy are present. These include self-propelledness, contingency, rationality, noninertial motion, and equifinality of behaviors (see Johnson, Shimizu, & Ok, 2007, for a review, and Csibra, 2008). Our claw control stimuli presented none of these cues; as such, we hypothesized that infants would not attribute goal-directedness to the claw's behavior.

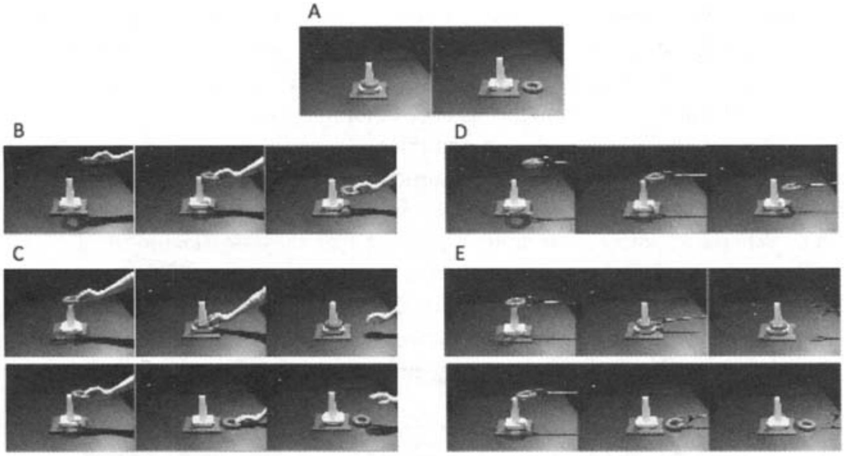

FIGURE 1 Stimuli presented to infants: (a) Baseline still pictures. (b) Hand habituation events. Hand holding ring enters, hits top of cone, moves toward ground and pauses in midair. Event loops. (c) Hand test events (used in hand and hand–test only conditions). Hand holding ring enters, places ring on cone, and leaves stage. Hand holding ring enters, hits top of cone, places ring next to cone, and leaves stage. Events do not loop. (d) Claw habituation events. Claw holding ring enters, hits top of cone, moves toward ground, and pauses in midair. Event loops. (e) Claw test events. Claw holding ring enters, places ring on cone, and leaves stage. Claw holding ring enters, hits top of cone, places ring next to cone, and leaves stage. Events do not loop.

Baseline trials. In all three conditions, infants' looking was first measured to two still-frame displays—one of the ring on the cone, and one of the ring laying beside the cone—to determine whether infants had a baseline looking preference to one of the end states presented during test events. Infants saw each display once, with order of presentation counterbalanced across infants.

Habituation. Infants in the hand and claw conditions were shown a brief movie (recorded from a live presentation) in which a yellow plastic cone (approximately 18 cm tall) sat in the center of a stage. Infants in the hand condition then saw an experimenter's hand attempt to place a blue plastic ring on the cone. A hand, holding the ring, entered the stage from the infants' right side. The hand traveled parallel to the floor of the stage until the ring made contact with the top of the cone, at which point the hand holding the ring bounced back at a 45° angle toward the floor (see Figure 1a). When the ring was approximately 10 cm from the floor

[2]In the hand condition, one baby failed to reach the habituation criterion in 14 trials. Removing this infant's data from the analyses did not change any of the reported results; thus, all infants are included in the following analyses. All infants in the claw condition habituated within 14 trials.

and approximately 15 cm from the base of the cone, the movie paused and then quickly faded to black. The entire event was approximately 3 sec in duration. This event looped continuously until the infant looked away from the monitor for 2 consecutive sec or if 30 sec elapsed. Infants' looking was recorded by an online observer blind to condition, beginning at the point of curtain raising, and indicated by the squeak. Trials were repeated until a habituation criterion was met (defined as three consecutive trials with summed looking time less than or equal to 50% of the summed looking times on the first three trials). Infants were presented with a minimum of 6 and a maximum of 14 habituation trials. Infants in the claw condition were exposed to nearly identical events, except that instead of a human hand, the ring was held by inanimate plastic claw (see Figure 1b). Speed and path of motion of the hand and claw were equated across habituation trials, such that the movies were identical in the approach of the hand and claw, the rebound of the hand and claw, and the total duration of the movies.[2]

Test events. Infants in all conditions saw two different test events, presented in alternating order. In intentionally consistent test events, the outcome of the event was consistent with the intended goal, but inconsistent with the physical trajectory of the hand (or claw) in the habituation trials, as the infants had never seen the goal completed during habituation events. The hand (or claw) entered from the infants' right and approached the top of the ring cone. The hand (claw) then placed the ring over the top of the cone and brought it to rest at the cone's base. It then released the ring and returned offstage to the infants' right. The movie then stopped with the ring resting on the cone with no hand or claw visible. Infants' looking time was recorded from the time the ring reached its final resting place at the base of the cone. This was indicated by the person in charge of raising and lowering the curtain, who tapped the blind observer on the shoulder to indicate that timing should commence. At this point, the blind observer determined whether the infant had been looking up to that point; if he or she had not, the trial was repeated. In trajectory consistent test events, the outcome of the event was consistent with the physical trajectory, but not with the goal to place the ring on the cone: The hand (claw) entered from the infants' right, hit the top of the tower, and bounced back toward the floor at a 45° angle (as in habituation events). The hand (claw) then continued along the same motion trajectory and placed the ring on the floor of the stage, next to the base of the cone. The hand (claw) then pulled back offstage to the infant's right. The movie then paused with the ring resting off the cone, with no hand or claw visible. Infants' looking time was recorded from the time the ring reached its final resting place on the floor next the cone, assuming they had watched the ring's movement toward this location. Importantly, the two test locations of the ring on the cone and the ring off the cone were both equidistant to the final location of the paused ring in habituation trials (each 15 cm away), so the infants could not distinguish the outcomes based on relative distance from the habituated final location.

Infants in each condition saw six alternating test events, with order of presentation counterbalanced across infants. A hidden observer, unaware of the order of events, measured looking time on each trial. A second experimenter, naive to the experimental hypotheses, reviewed video footage on 30% of experimental trials and measured infants' looking times to the test events. Agreement between the two coders was high ($r = .98$), thus all data analyses were performed using results from the online timing.

Experience. To determine whether infants' looking times were influenced by their experience with stacking toys, parents were asked after the study whether their infants had a similar toy at home.

RESULTS

Infants' looking times to the test events are depicted in Figure 2. We performed a mixed-design ANOVA with condition (hand, hand–test only, and claw) as a between-subjects factor and test event (ring placed on cone versus ring placed next to cone) as a within-subjects factor. This analysis revealed a significant interaction between condition and test event, $F(2, 33) = 5.902, p < .01$. As predicted, infants in the hand condition looked reliably longer during events in which the ring was placed next to the cone ($M = 4.2$ sec) than to events in which the ring was placed on the cone ($M = 2.3$ sec), $t(11) = 3.70$, two-tailed $p < .005$. Infants in the hand–test only condition who were presented with baseline and test trials only did not look

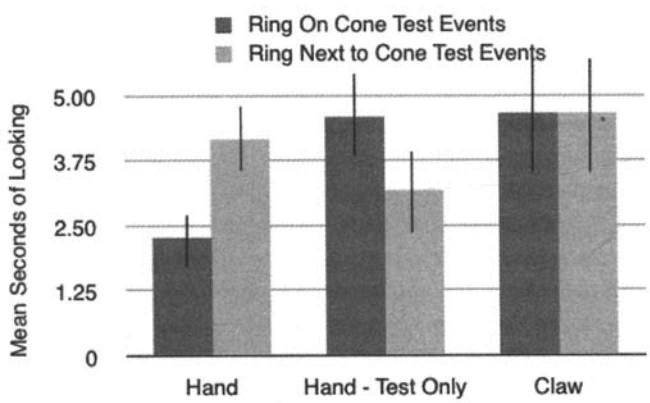

FIGURE 2 Mean amount of looking averaged over trials to the test events ending with the ring on and off the cone in the hand, hand–test only, and claw conditions.

reliably longer at off-cone events ($M = 3.2$ sec) than at on-cone events ($M = 4.6$ sec), $t(11) = -1.66, p > .12$. This result is significantly different from infants' looking to the test events in the hand condition, $F(1, 22) = 11.53, p < .005$.

Infants in the claw condition looked equally long at the on-tower and off-tower test events (Ms = 4.7 sec and 4.7 sec, respectively, $p > .95$. Importantly, these effects did not appear to stem either from differences in habituation rates or overall looking times between infants in the hand and claw conditions: Infants in both conditions habituated in an average of eight trials, and their mean amount of looking on the last three habituation trials did not differ ($M_{hand} = 5.54$ sec, $M_{claw} = 6.56$ sec), $t(22) = -.65, p > .5$. Additionally, there was no main effect of condition on average looking summed over both test events, $F(1, 22) = 1.53, p > .22$, suggesting that infants were not overall more interested in hand test events than claw test events.[3]

Finally, the duration of infants' looking to baseline trials (static images of the ring on and off the cone, prior to habituation) were not significantly different in any condition, $F(2, 33) = .06, p > .94$; all paired ts $p > .75$, suggesting that infants did not find either of the outcomes to be less interesting overall. Further analyses indicated that there were no effects of either sex of infant or order of presentation (both Fs < 1). Analysis of the nonparametric data revealed that in the hand condition, 11 of 12 infants looked longer at trajectory consistent than intentionally consistent test events ($p < .01$, via a binomial test). In contrast, in the hand–test only condition, only 4 of 12 infants looked longer at the trajectory consistent events ($p > .38$). In the claw condition, 6 of 12 infants looked longer at trajectory consistent test events ($p > .99$). These differences are significant via a Fisher's Exact test, $p = .01$.

Experience

As we assessed infants' experience with stacking cones only after the babies had participated in the study, whether or not they had seen the toy did not influence whether they were placed into the hand, claw, or hand–test only conditions. We were able to obtain experience information from 10 of 12 infants in the hand condition (8 infants had experience, 2 did not), 10 of 12 infants in the claw condition (3 infants had experience,

[3]As is visible in Figure 2, infants look longer to both claw outcomes and to the inconsistent hand outcome than they do to the consistent hand outcome. Although this might seem inconsistent with the claim that infants are "surprised" by the uncompleted goal in the hand condition (indeed, they seem additionally "surprised" by both claw test events), it is consistent with our claim that infants habituate to an unseen goal. Despite not having seen the outcome of the failed attempt during habituation, its presentation in test does not peak infants' attention. This result is consistent with many other looking time studies that use inanimate controls (e.g., Cisbra et al., 2003; Woodward, 1998), which find that infants look least to the consistent animate test events, and look equally more to inconsistent animate and to both types of inanimate test events. One possibility for this pattern is that both claw test events represent a change from habituation (e.g., they did not loop) and in the ambiguous claw condition, this change was enough to peak the infants' interest in both event types.

7 did not), and 12 of 12 infants in the hand–test only condition (7 infants had experience, 5 did not). There is a marginally significant effect of condition and experience (Fisher's Exact test, $p = .08$), with more infants in the hand condition having experience than in the claw condition; however, adding experience as a covariate to the analyses revealed no effect of experience in any condition, to either baseline or test events (all $p > .25$), suggesting that having experience with stacking cones did not make infants more likely to prefer one test outcome or to interpret the event as goal-directed.

DISCUSSION

The results of this experiment suggest that infants (a) can infer unfulfilled goals by 8 months of age, (b) do so when some of the physical information provided is irrelevant or inconsistent to the intended goal, (c) habituate to the completed goal, despite its remaining unseen throughout habituation, and (d) apply their inferences about unseen goals to animate agents, but not to inanimate objects. Thus, we did not find evidence that infants had trouble inferring unfulfilled goals that required more than simply reading ahead in a physical trajectory; instead, infants' success in the current tasks suggests that they are able to ignore goal-irrelevant physical information when interpreting the intended end states of failed attempts.

To determine the intended outcome of the event, infants needed to note the affordance relationship between the ring and the tower. Some infants might have been able to note this relationship through their experience with ring-stacking toys; however, not all of our infants had this experience. Additionally, our control conditions suggest that infants used this affordance relationship only selectively: Despite the affordance between ring and cone being present in all conditions, infants did not attribute the goal to place the ring on the cone to an inanimate agent, nor to a hand that they had not previously seen involved in a failed attempt. These results suggest that although the physical relationship between the ring and the cone was available to the infants in all conditions, they only used it in the scenario in which an ambiguous intentional action was present. These results suggest that infants were indeed being habituated to the unseen goal, rather than to the affordance relationship between the ring and the cone, and that the affordance relationship was used to guide their identification of the goal.

This result begs the question of exactly what infants are doing when presented with behaviors in the world, and what sort of processes lead them to make intentional attributions in some cases, and not in others. We suggest that finding goal-directed entities and assigning goals to their behaviors is fundamental to how infants see the world. Indeed, we believe that infants did not distinguish between the test events in either of our control conditions for two very different reasons: In the hand–test only control condition, infants did not distinguish the test events because they saw both test events, a hand placing the ring on the cone and off the cone, as being goal-directed, as all the necessary cues of goal-directed behavior were present (a human was performing the action, the motion looked deliberate, and the hand completed an event in both cases). Indeed, although placing a ring next to a ring tower might appear odd to adults, presumably infants see adults perform goal-directed events that appear nonsensical to them all the time. Given cues that an adult is content with his or her actions, assuming that the behavior was in fact intended might help young children learn about the kinds of things adults do and the ways in which they do them (see Lyons, Young, & Keil, 2007). In contrast, in the claw control condition, despite the repeated motion and obvious physical affordance between the ring and the cone (which all infants were shown in the baseline events), there was no agent present, and thus infants were not motivated to perform an intentional analysis of the scene at all. As the physical scene presented to them during habituation was ambiguous as to an obvious ending, neither test event appeared more interesting. These findings point to the impressive selectivity of even young infants' interpretation of the social world.

Eight-month-old infants' success in an unfulfilled goal context is impressive, as previous research has shown infants at this age failing at unfulfilled goal tasks (Brandone & Wellman, 2009; Csibra et al., 2003). This study supports the conclusion that younger infants, too, might be capable of inferring the unfulfilled goals of others (see also Daum et al., 2008; Hamlin et al., 2008), even when the physical action includes trajectory information that does not specifically identify an end goal. Why did our young infants succeed when others have failed? The answer is not obvious, but we suggest that even though our stimuli required active interpretation of the habituation scenes to identify that there was an unfulfilled goal present, and that infants could not use trajectory information alone to determine what the goal was, that once they had done inferred some goal, identifying it was not necessarily difficult (indeed, we had shown the salient affordance between the ring and the cone to all infants in the baseline trials). Additionally, many (but not all) studies of unfulfilled goal understanding to complex events have utilized imitation measures (Carpenter et al., 1998; Johnson et al., 2001; Meltzoff, 1995), whose outcomes might be constrained by young infants' physical limitations. Our use of a looking time measure might have allowed us to tap infants' knowledge at an earlier age, as 8-month-old infants are largely incapable of putting rings on cones themselves. These findings enrich the evidence for mature goal understanding early in development, and further research should attempt to explore the relationship between the physical aspects of intentional actions (e.g., trajectory and affordances) and goal understanding.

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