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Preverbal infants identify emotional reactions that are incongruent with goal outcomes

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ABSTRACT

Identifying the goal of another agent's action allows an observer to make inferences not only about the outcomes the agent will pursue in the future and the means to be deployed in a given context, but also about the emotional consequences of goal-related outcomes. While numerous studies have characterized the former abilities in infancy, expectations about emotions have gone relatively unexplored. Using a violation of expectation paradigm, we present infants with an agent who attains or fails to attain a demonstrated goal, and reacts with positive or negative affect. Across several studies, we find that infants' attention to a given emotional display differs depending on whether that reaction is congruent with the preceding goal outcome. Specifically, infants look longer at a negative emotional display when it follows a completed goal compared to when it follows a failed goal. The present results suggest that infants' goal representations support expectations not only about future actions but also about emotional reactions, and that infants in the first year of life can relate different emotional reactions to conditions that elicit them.

1. Introduction

Success in a social environment depends on capacities to understand, anticipate, coordinate with, and learn from the behavior of others. Human adults readily solve these problems by relying on intuitive knowledge of other minds that specifies the causal relationships linking various mental states to each other, to events or conditions in the external environment, and to overt action (Wellman, 1990; Wellman & Gelman, 1992; Carey, 1985; Gopnik & Meltzoff, 1997). On this basis of this knowledge, a perceiver can recover goals and other mental states from observed behavior (Baker et al., 2009, 2011), and recruit these mental state representations for a range of inferences. For example, we rely on goals or intentions to socially evaluate other agents (e.g. Cushman, Young, & Hauser, 2006; Young & Saxe, 2009), to interpret speech and other communicative acts (e.g. Goodman & Stuhlmüller, 2012; Smith, Goodman, & Frank, 2013), and to reason about an agent's emotional state in different contexts (e.g. Parkinson, 2007; Siemer & Reisenzein, 2007; Zaki, Bolger, & Ochsner, 2009).

The present research probes the development of this last set of inferences, specifically the ability to predict the emotional consequences of goal-related outcomes. Prior studies using verbal vignettes and pictorial scenarios suggest that young children can identify how a target will feel in response to a particular event (Wellman & Wooley, 1990): by 2–3 years of age, children reason about emotions as well as desires and preferences, inferring others' emotional states in the absence of overt reactions (e.g. Russell, 1990; Wellman & Banerjee, 1991; Wellman & Bartsch, 1988; Yuill, 1984; for related findings with younger children, see Chiarella & Poulin-Dubois, 2013; Vaish, Carpenter, & Tomasello, 2009). To investigate the origins of this knowledge, the present research examines whether basic emotion inferences might be evident in preverbal infants.

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By midway through first year of life, humans attend to the intentional movements of others and appear to encode goal-relevant properties of these movements, such as the objects to which they are directed, over more superficial properties, such as their trajectories (Gergely, Nádasdy, Csibra, & Bíró, 1995; Woodward, 1998). On the basis of observed actions, infants form expectations both about the outcome of future actions (Bíró & Leslie, 2007; Csibra, Bíró, Koós, & Gergely, 2003; Jovanovic et al., 2007; Woodward, 1998) and about the means that will be exploited under different physical constraints (Gergely et al., 1995; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Phillips & Wellman, 2005). One interpretation of these and other findings (e.g. Kovács, Téglás, & Endress, 2010; Luo & Baillargeon, 2005; Luo & Johnson, 2009) is that infants exploit abstract principles to make sense of the movements of others, integrating several relevant variables (outcomes, paths, physical obstacles and barriers to perception) to identify an agent's goal and anticipate future behavior. On this view, early representations of goal-directed behavior are embedded in a coherent inferential framework for predicting and explaining action (Bíró, Verschoor, & Coenen, 2011; Carey, 2009; Luo & Baillargeon, 2010).

Others have avoided appeal to abstract inferential principles, explaining these phenomena in terms of domain-general associative or statistical learning mechanisms operating over sensory or motoric representations (e.g. Paulus, 2012; Paulus et al., 2011; Rakison, Cicchino, & Hahn, 2007). In fact, some have argued that infants could exhibit expectations about the path of an action in these experiments without having any representation of the action as goal-directed (Paulus et al., 2011). Moreover, even among theories that grant abstract goal knowledge to infants, early accounts posited a relatively limited inferential mechanism; Gergely, Csibra and colleagues, for example, proposed that infants represent actions by assuming a *teleological stance*, analyzing the path an entity takes, the outcomes it achieves, and the physical constraints of the environment, in accord with an assumption that actions are efficient with respect to goals (Gergely & Csibra, 2003; Gergely et al., 1995). This mechanism, at least as initially described, would operate over observable variables to form an abstract action representation, but would not posit subjective epistemic states, or other internal psychological states such as emotions.

One way to distinguish between these possibilities is to examine the range of inferences supported by early goal-representations. Upon observing a goal-directed action, are infants' predictions limited to the path a subsequent action will take and the end state it will achieve, or do infants form a broader set of expectations? In particular, the present research explores whether preverbal infants have expectations about the affective states that are likely to result from different goal outcomes. Despite decades of research on infants' abilities to process and interpret emotional displays (e.g. Field et al., 1983; Grossmann, 2010; Moses, Baldwin, Rosicky, & Tidball, 2001; Nelson, 1987; Walker-Andrews, 1997), there is little evidence to date that infants have knowledge of the eliciting conditions for different emotions. In fact, several findings suggest that young infants might fail to understand the relations between goals and emotions.

First, Repacholi and Gopnik (1997)found that whereas 18-month-old toddlers could use an agent's positive emotional expression towards a food item to guide their sharing behavior (see also Egyed, Király, & Gergely, 2013), 14-month-olds ignored the target's expressed emotion and provided her with the item they themselves preferred. However, this failure could have resulted from conflict between the partner's preference and the child's own preference, which must be suppressed in order to help according to the partner's desire. To eliminate these demands, Vaish and Woodward (2010) used a looking time paradigm investigating whether infants this age could use an agent's emotional expression to predict her subsequent action. Specifically, infants viewed an agent direct attention and emotion towards one of two objects, and then reach either towards the attended or unattended object. Fourteen-month-old infants looked longer when the agent reached towards the unattended object, regardless of whether her expressed emotion had been positive or negative. The authors interpret this pattern as evidence that infants did not understand the relation between emotion and goal-directed action. Because emotion cues conflicted with attentional cues, however, it is possible that infants failed to use emotional information because another salient and relevant cue was provided. Infants might nevertheless represent the relations between emotions and goals by this age, and exhibit such understanding in contexts that eliminate these competing demands.

Thus, despite the abundance of research on action understanding in infancy, additional research is needed to characterize the full scope of early goal knowledge, and the trajectory of developmental change in these abilities. In the present studies, we begin to fill this gap by investigating whether preverbal infants form expectations about emotional reactions to goal-relevant outcomes. If infants can represent the affective consequences of achieving or failing to achieve a goal, they should be sensitive to whether an agent's emotional reaction is consistent with an observed outcome. We were particularly interested in infants between 8 and 10 months of age, given conflicting reports of change and continuity in social cognitive abilities through this range (see Beier & Spelke, 2012; Luo, 2010; Senju & Csibra, 2008; Tomasello, Carpenter, Call, Behne, & Moll, 2005; Woodward, 2003).

2. Experiment 1

In Experiment 1, we familiarized infants with events in which an agent pursued a goal (reaching a mat in a particular location) by repeatedly moving to that location, modifying its path based on the constraints of the environment. We then presented events in which the agent either successfully completed or failed to complete this goal, and exhibited an emotional response that was congruent or incongruent with the outcome. If infants link goal outcomes to emotional reactions, they should exhibit heightened attention to events in which there is a mismatch between the outcome and the target's affective response.

2.1. Method

2.1.1. Participants

This study was conducted at the Laboratory for Developmental Studies on Harvard University's campus. Thirty-two 10 month-old infants (15 females) and thirty-two 8 month-old infants (12 females) were tested. An additional nine infants also were tested but were excluded from the data analysis because of fussiness/inattention ($n = 4$), parental interference ($n = 1$), looking time more than 3 standard deviations above the mean ($n = 1$), equipment failure ($n = 1$), or online coding error ($n = 2$). All the infants were healthy, full-term (at least 36 weeks gestation), and living in the greater Boston/Cambridge area.

2.1.2. Apparatus

The events presented in this experiment consisted of animated sequences of actions and emotional reactions. The events were presented using Keynote software running on a MacBook Pro computer connected to an LCD projector. Infants viewed the events on a large screen ($\sim$1.2 m $\times$ 1.7 m) while seated on a parent's lap in a darkened experimental room, at a viewing distance of approximately 1.5 m. A video camera was mounted below the screen and positioned behind a small hole in a black curtain to achieve a clear image of the infant's face without creating a visual distraction.

2.1.3. Displays

Computer-animated events were created using Keynote software. The events involved two simple geometric characters: red and purple circles whose schematic faces had small distinguishing features (e.g. different ears and hair) and could assume different expressions. Infants first viewed emotion-familiarization trials (to ensure that the emotional displays were not entirely novel when presented during test trials) in which the two agents were presented on opposite sides of the screen. One agent exhibited a single positive reaction, in the form of an upturned smile appearing on the face, accompanied by a child-like giggling sound, and a small bouncing movement. The other agent exhibited a single negative emotional reaction, which involved a downturned frown, as well as an infant crying sound (from stimuli reported in Johnson, Dweck, & Chen, 2007) and a slow, side-to-side rocking movement. These reactions occurred sequentially, each lasting for 7 s. In a second emotion-familiarization trial, each agent exhibited the opposite reaction from that expressed during the first trial.

Test trials consisted of five goal-familiarization events (see Fig. 1a) in which one of the two agents appeared and engaged in a goal-directed action of moving towards and stopping on a gray square mat. In the first two of these events, the agent moved in a straight path towards the goal. For the following three goal-familiarization events, a barrier appeared, changing in height on each familiarization, and the agent jumped from off screen, adjusting its jump to the height of the barrier. On the third and fourth familiarization events, the agent successfully jumped over the barrier to reach the goal location. On the fifth goal familiarization, the barrier became even higher, and the agent failed to surmount the barrier, instead hitting it and rolling back to the side of entry. These events occurred in rapid succession.

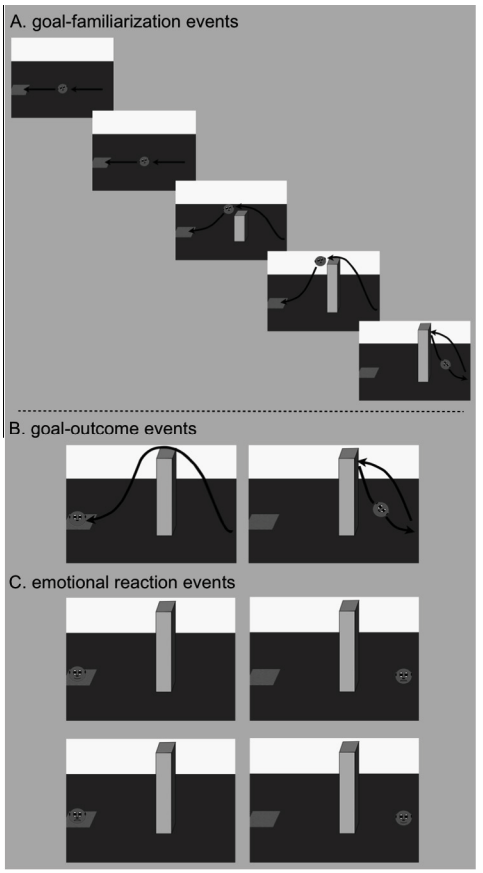

Fig. 1. Trial structure for Experiment 1. For each of four trials, infants viewed five goal familiarization events (A), followed by a goal-outcome event (completion or failure, B), followed by an emotional reaction event (positive or negative, C).

Infants then viewed a goal-outcome event in which the agent engaged in a second attempt towards the goal, and either completed the goal (surmounting the barrier and reaching the goal location) or failed to complete the goal (hitting the barrier and tumbling back down to the starting point) (see Fig. 1b). The agent then exhibited one of the two emotional reactions described above (Fig. 1c).[1] The emotional reaction was shown once, and subjects were excluded for inattentiveness if they did not look to the screen during any part of the emotional display.

2.1.4. Design

Infants viewed a total of four test trials, each involving 5 goal familiarization events followed by a goal-outcome

[1] To validate these stimuli, we showed the same animations to 72 adults on Amazon's Mechanical Turk and asked them to rate the "strangeness" of the character's reaction on a scale from 1 (not at all strange) to 7 (extremely strange). Adults judged the incongruent reactions as more strange for both completed and failed goal videos. Mean(SEM): Completed goal/Positive affect = 3.61(0.57), Completed goal/Negative affect = 5.00(0.53), Failed goal/Positive affect = 5.74(0.33), Failed goal/Negative affect = 3.06(0.50).

event and an emotional reaction event. Since subjects might have been confused by a single agent who completed its goal and failed to complete the goal on different trials, two different agents were presented, one who succeeded in both test events and one who failed in both events. Thus, one agent successfully completed its goal and responded with positive emotion on one trial and negative emotion on the other. In the two remaining trials, the other agent failed to complete its goal and responded with either positive or negative emotion. Thus, each subject viewed all four test trial types: *completed-positive (congruent)*, *complete-negative (incongruent)*, *failed-negative (congruent)*, *failed-positive (incongruent)*. Subjects viewed two reactions of a given emotion (following a failed or completed goal), and two reactions of the opposite valance (maintaining the order of failure and completion). Trials were therefore presented either in the order of *incongruent–congruent–congruent–incongruent* or *congruent–incongruent–incongruent–congruent*. Between subjects, we counterbalanced whether the first trial involved a failed or completed goal, whether the first emotional response was positive or negative, which agent exhibited which test trial type, and the order and side of the screen on which emotions were introduced during emotion-familiarization trials.

2.1.5. Procedure

Stimuli were presented to infants by an experimenter behind a curtain in the testing room, and live video of the infants' face was fed to an adjacent coding room. A second experimenter viewed the infant's face on a television monitor and coded the infant's attention to the display by pressing a button when the infant was attending to the screen. Prior to presentation of the displays, the second experimenter was calibrated to the relevant gaze locations by the first experimenter calling the subject's attention to the middle of the screen and to each of the screen's edges. The coder's responses were tracked using the Xhab64 software program, which signaled the experimenter in the testing room to progress to the next trial after a pre-established attentional criterion. Both experimenters, including the experimenter presenting the stimuli, were blind to the visual events presented to the infant, and thus to which trials were congruent or incongruent for a given subject. Caregivers were instructed to keep their eyes closed throughout the entirety of the session. Infants' attention was called to the screen at the beginning of the session by the experimenter saying "Hi, [baby's name], look at this!".

For the two emotion-familiarization trials, looking time was recorded from the start of the first emotional vocalization in the event, and continued until the infant had disengaged attention from the screen for 2 consecutive seconds or had reached a maximum of 45 s of total looking time. Infants then viewed the test trials, each involving five brief goal familiarizations followed by a goal-outcome event and an emotional reaction event (see Fig. 1). During reaction events, looking time duration was again recorded from the start of the emotional vocalization and continued until the infant looked away for 2 s or reached 45 s of total looking time. This entire sequence was repeated for each of four test trials.[2]

2.1.6. Coding and analyses

In order to present events with trial duration contingent on the infant's attention, online coding was conducted by a researcher in an adjacent room (blind to condition), as described above. Looking times were then coded offline (also blind to condition), and the latter were used for analysis. Another researcher coded 100% of sessions, and these two offline coding measures were highly correlated, $r = 0.95$. To directly test for bias in the coding, we calculated the difference between the main coder and the reliability coder for each trial, and assigned a positive or negative sign to the difference score depending on whether or not it was in the direction of the hypothesis. These values did not significantly differ from zero ($M = -0.179$, $t(255) = -1.293$, $p = 0.197$). We conducted a repeated measures ANOVA with completion (completed goal vs. failed goal) and congruency (incongruent reaction vs. congruent reaction) as within-subject factors and age group (8 vs. 10 months) as a between-subjects factor.

2.2. Results

At both ages, infants looked longer at the incongruent emotional reactions, an effect driven primarily by longer looking to negative affect following a completed goal (Fig. 2). The ANOVA revealed a main effect of congruency ($F(1,62) = 12.451$, $p = 0.001$), with infants looking longer at incongruent emotional reactions ($M = 13.825$) than congruent reactions ($M = 11.713$). There was no interaction between congruency and age group ($F(1,62) = 0.581$, $p = 0.449$), and follow up analyses revealed no main effects of any of the counterbalancing factors (familiarization valence order, familiarization start side, test valence order, and test congruence order). In addition to the predicted effect of congruency, there was a trend towards a main effect of completion ($F(1,62) = 3.8841$, $p = 0.053$). To clarify the nature of this effect, we conducted separate *t*-tests comparing congruent and incongruent reactions for completed and failed goals separately. There was an effect of congruency for the completed goal test events ($t(63) = 3.169$, $p = 0.002$) but not for the failed goal test events ($t(63) = 1.103$, $p = 0.274$). Thus, the main effect of congruency appears to be driven by longer looking to the negative emotion following a completed goal. Nevertheless, the congruency $\times$ completion interaction was not significant ($F(1,62) = 2.191$, $p = 0.144$). To confirm that both age groups exhibit sensitivity to emotional congruency, we conducted a separate repeated measures ANOVA for each age group and found main effects of congruency in the 10-month-old group ($F(1,31) = 4.159$, $p = 0.050$) and in

[2] For the 10-month-old infants, this set of four test trial types was presented a second time, yielding a total of eight test trials per subject. However, it became clear over the course of testing that eight test trials was too demanding on subjects' attention, as many did not complete the second test set. All reported analyses in Experiment 1 are conducted on the first test set only, and all subsequent studies (including the 8-month-old age group of Experiment 1, and the conceptual replication in Experiment 3) included only one test set per subject.

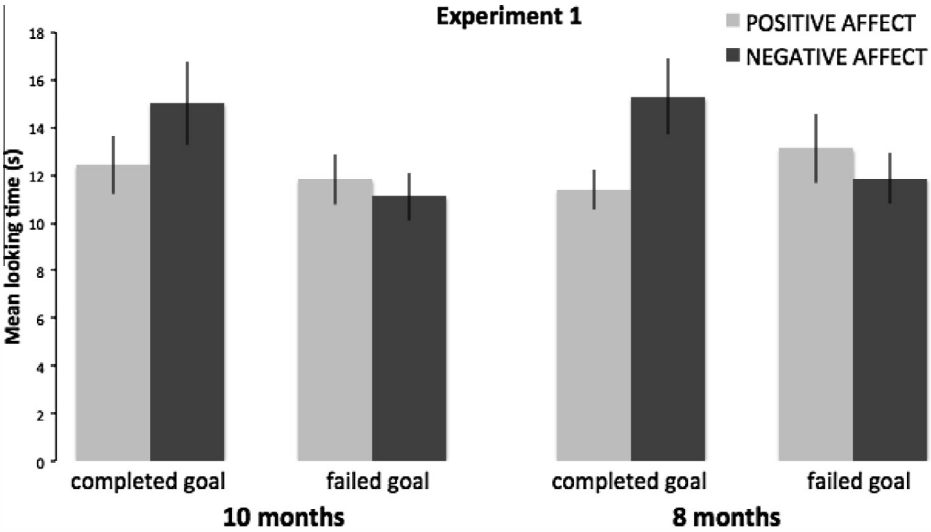

Fig. 2. Experiment 1 results. Mean looking time to test trials in Experiment 1 for each age group. Error bars indicate SEM.

the 8-month-old group ($F(1,31) = 8.524$, $p = 0.006$). There were no differences in infants' looking time to the emotion-familiarization trials (Mean(SEM): positive–negative familiarization = 19.64(0.10) s, negative–positive familiarization 19.65(0.15) s).

2.3. Discussion

In Experiment 1, infants' looking time to the very same emotional display differed depending on whether the reaction was consistent with the preceding action context. In particular, infants looked longer at a negative emotional display when it followed successful goal completion, suggesting that infants were sensitive to the mismatch between the situation and the emotional response. We observed no difference between the two age groups studied. Based on these results, we suggest that by 8 months of age infants have some knowledge of the conditions that elicit different emotions in others, and can detect when emotional reactions do not fit with the preceding goal context.

If this interpretation is correct, and infants exhibit differential attention to positive and negative displays based on an analysis of the goal outcome, infants should show this effect only if they are able to identify the agent's goal during the familiarization phase. To test this prediction, we presented infants with a paradigm in which the test events were identical, but a stable goal could not be inferred from the familiarization trials (see similar controls in Csibra, Gergely, Bíró, Koos, & Brockbank, 1999; Gergely et al., 1995). By using the same test displays as Experiment 1, this condition helps to control for various low-level differences between the two test events (i.e. faster downward motion in the failed goal case), and for baseline preferences for one of the two emotional reactions or one of the two outcomes.

3. Experiment 2

In Experiment 2, infants viewed outcome and reaction events identical to those in Experiment 1 (an agent sailing over a barrier and landing on the mat, or colliding with the barrier and tumbling to the ground) but were given no evidence during the familiarization events that the character had a stable goal. Instead of viewing familiarization events in which the character engaged in rational, equifinal movement towards a constant goal, infants were familiarized with events in which the agent moved to different locations on each trial via paths that did not match the environmental constraints. If the results of Experiment 1 depend on infants identifying the agent's goal and outcomes that are consistent or inconsistent with it, they should show no expectations about emotions in this experiment. Alternatively, if this pattern of results was driven by some low-level property of the displays (e.g. the relationship between the agent's speed of motion during the outcome event and the reaction event) or by other differences between the failed goal and completed goal trials, the effect should be maintained in this experiment.

3.1. Method

3.1.1. Participants

Thirty-two 10 month-old infants (15 females) and thirty-two 8 month-old infants (13 females) participated in this study. An additional eight infants were also tested but were excluded from data analysis because of fussiness/inattention ($n = 4$) or online coding error ($n = 4$). All the infants were healthy, full-term (at least 36 weeks gestation) and living in the greater Boston/Cambridge area.

3.1.2. Apparatus/procedure

The apparatus and procedure were identical to those reported for Experiment 1.

3.1.3. Displays

The outcome and reaction events were identical to those of Experiment 1, but the familiarization events differed. The movements were similar to those in the goal-familiarization events in Experiment 1 (straight or arching

paths across the screen), but were not efficient with respect to any stable goal. The movements began and ended in arbitrary, varying locations on each event and were not efficient with respect to environmental constraints (e.g. taking an arched path when no obstacle was present; see Fig. 3). Subjects then saw the agent begin an arched trajectory across the screen, either sailing over the barrier and landing on the mat, or hitting the barrier and tumbling back down, followed by a positive or negative emotional reaction. These reactions events could be construed as congruent or incongruent with respect to the physical outcome (landing on mat or colliding with barrier), but could not be interpreted in terms of a stable goal of the agent.

3.1.4. Coding and analyses

The coding procedure was identical to Experiment 1. Another researcher coded 27% of sessions, and these two offline coding measures were highly correlated, $r = 0.90$. The principal analysis was as in Experiment 1. A further analysis with the additional factor of experiment (1 vs. 2) compared infants' test trial looking times across the two experiments.

3.2. Results

At both ages and in both outcome conditions, infants looked equally at the test events with congruent and incongruent emotional reactions (Fig. 4). In contrast to Experiment 1, there was no main effect of congruency ($F(1,62) = 0.585$, $p = 0.447$), with infants looking equally to incongruent emotional reactions ($M = 11.702$) and congruent reactions ($M = 12.233$). There was no interaction between congruency and age group ($F(1,62) = 0.914$, $p = 0.343$), and follow up analyses revealed no main effects of any of the counterbalancing factors (familiarization valence order, familiarization start side, test valence order, and test congruence order). As in Experiment 1, we conducted a separate repeated measures ANOVA for each age group and found no effect of congruency in either the 10-month-old infants ($F(1,31) = 1.117$, $p = 0.299$) or the 8-month-old infants ($F(1,31) = 0.027$, $p = 0.870$). To compare directly the effect of congruency in Experiments 1 and 2, we conducted a repeated measures ANOVA with event valence (completed vs. failed goal in Experiment 1, pass over barrier vs. hit barrier in Experiment 2) and congruency (congruent vs. incongruent reaction) as within subjects factors and experiment (Experiment 1 vs. Experiment 2) as a between subjects factor. This revealed a significant congruency $\times$ experiment interaction ($F(1,126) = 8.314$, $p = 0.005$). Congruency $\times$ experiment interactions were also observed when separately analyzing 10-month-old infants ($F(1,62) = 4.195$, $p = 0.045$) and 8-month-old infants ($F(1,62) = 4.116$, $p = 0.046$). Infants' looking times for the two emotion-familiarization trials did not differ (Mean(SEM)): positive–negative familiarization = 19.89(0.14) s, negative–positive familiarization 18.52(.13) s).

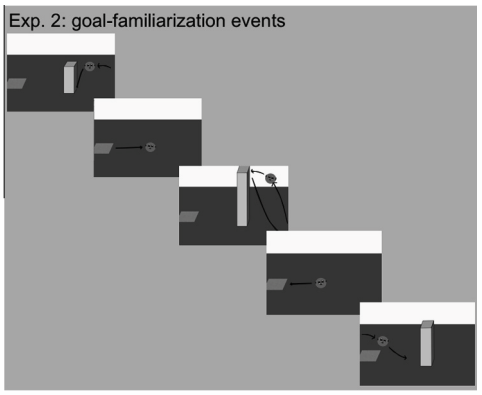

Fig. 3. Familiarization events for Experiment 2. For each of four trials, infants viewed five familiarization events in which the agent performed simple movements comparable to those performed in Experiment 1, but without a stable goal. The outcome and reaction events were identical to Experiment 1.

3.3. Discussion

The results of Experiment 2 suggest that differences in infants' attention to positive and negative affect following the completed goal events depend on prior identification of the agent's goal during the familiarization. The previous results are therefore unlikely to have been driven by superficial variables that differed across these test conditions, such as differences in the speeds and directions of the agents' motions. However, the congruency effect in Experiment 1 was driven primarily by an effect in the completed goal trials. In Experiment 3, we replicate the results of Experiment 1 and investigate this possible difference between the failed and completed goal contexts.

4. Experiment 3

Experiment 3 investigated whether infants would distinguish congruent from incongruent reactions in a scenario that involved a superficially different goal than Experiment 1 (an object-based rather than a location-based goal) and a different set of environmental constraints. This experiment provided a conceptual replication of Experiment 1, as well as a means of exploring the potential asymmetry between completed and failed goal conditions. In Experiment 1, infants exhibited violation of expectation to the negative emotion following a completed goal, but no response to the positive emotion following a failed goal. Could particular aspects of the goal context used in Experiment 1 explain this pattern? Infants in Experiment 1 viewed a goal familiarization in which the agent failed to achieve the goal but did not react emotionally, and then a test trial in which the agent made a second attempt followed by an emotional response. It is possible that the absence of an emotional response following the failed goal familiarization weakened infants' expectations about the failed outcome event, either by presenting evidence that the agent's investment in the goal was weak, or by suggesting that the agent would repeat the action until success. To test this possibility, we removed the failed goal-familiarization event in the present experiment.

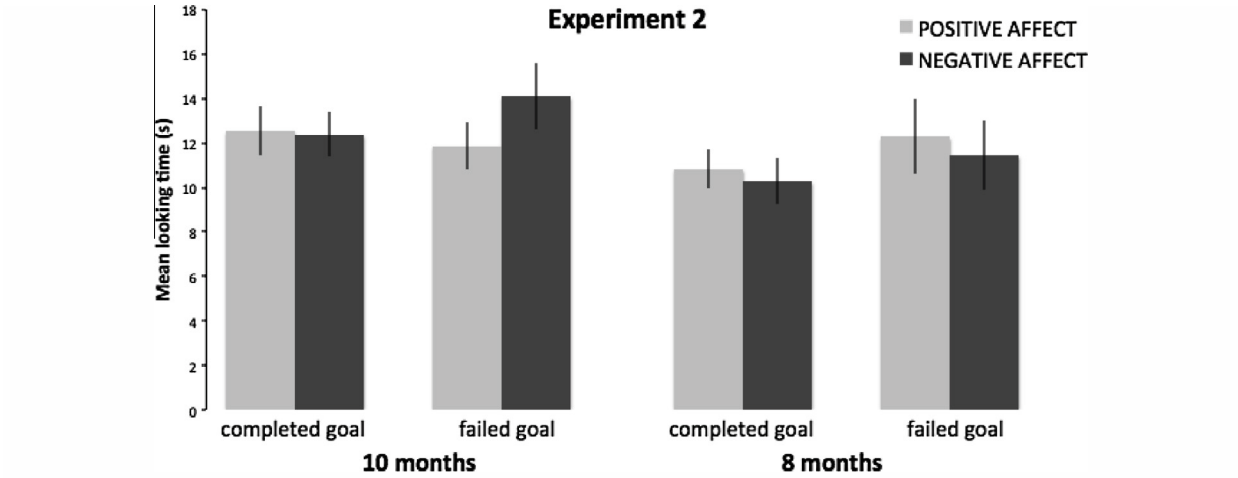

Fig. 4. Experiment 2 results. Mean looking time to test trials in Experiment 2 for each age group. Error bars indicate SEM.

The failed action in this experiment also differed from that of Experiment 1 in that the barrier that prevented the agent from reaching the goal appeared after the agent began to move toward the object. Thus, when the agent initiated its path towards the goal, there was no evidence of a physical obstacle. In Experiment 1, the obstacle was visible to the agent throughout the event, such that the agent may have had low expectations about the possibility of obtaining the goal. Given that losses are experienced as more negative when a reward is expected (Schultz, Dayan, & Montague, 1997), we aimed to set up a context in which the agent clearly expected to obtain the goal but was thwarted unexpectedly. In Experiment 3, the agent began moving towards the goal object with no apparent obstacle, and the agent's action was impeded mid-pursuit by the sudden introduction of a barrier. In all the outcome events, a large obstacle dropped in front of the agent as it moved towards the goal object. Completed and failed outcomes differed in the location of the object with respect to the obstacle. In failed goal trials, the obstacle fell between the agent and the goal object; in the completed goal trials, the object stood between the agent and the fallen obstacle, and therefore remained accessible to the agent.

4.1. Method

4.1.1. Participants

Twenty-four 10 month-old infants (15 females) and twenty-four 8 month-old infants (11 females) participated in this study. A larger sample size was used in Experiments 1 and 2 because these experiments were the first investigation in this domain. Given that Experiment 3 was a conceptual replication of the robust effect in Experiment 1, we collected a smaller sample (one comparable to other studies using similar methods). An additional nine infants were also tested but were excluded from the data analysis because of fussiness/inattention ($n = 5$), parental interference ($n = 1$), experimenter error ($n = 2$), or online coding error ($n = 1$). All the infants were healthy, full-term (at least 36 weeks gestation) infants living in the greater Boston/Cambridge area.

4.1.2. Apparatus/procedure

The apparatus and procedure were identical to those reported for Experiments 1 and 2.

4.1.3. Displays

The displays of affect during emotional reaction events were identical to those in Experiments 1 and 2. The emotion-familiarizations were similar, but rather than the two agents appearing on either side of the screen, a single agent was presented in the center of the screen during each emotional display. In the goal-familiarization events, an agent engaged in a repeated goal-directed action of moving towards and stopping next to a goal-object (a large ball). There were again four trials, each involving an outcome event and a reaction event, preceded by 5 brief goal-familiarization events (see Fig. 5a). In the first two goal-familiarizations, an agent moved in a straight path towards the goal. In the following two goal-familiarizations, a barrier appeared and the agent updated its path to move around the barrier, coming to rest next to the goal object. On the fifth familiarization a very large barrier appeared and the agent successfully jumped over the barrier to reach the goal location. These goal-familiarization events occurred in rapid succession.

During the outcome events (see Fig. 5b), no barrier was present and the agent initiated a straight path towards the goal object. Then, mid-event, a large obstacle fell from the top of the screen, landing in front of the agent. In both completed and failed events, the agent slowed down and came to rest without contacting the barrier. The only difference between these events was whether the goal object was positioned such that the barrier fell between the agent and the goal-object, preventing the agent from completing its goal, or fell on the far side of the goal object, allowing the agent to complete its goal. The agent then reacted with one of the emotional displays used in Experiments 1 and 2.

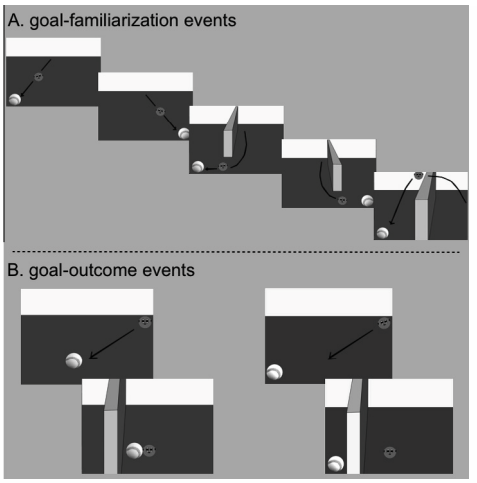

Fig. 5. Trial structure for Experiment 3. For each of four trials, infants viewed five goal familiarization events (A). They then viewed a goal-outcome event (B) in which an obstacle fell in front of the agent (on the failed goal trials, the obstacle blocked access to the object, whereas on the completed goal trials the object was still accessible). The agent then exhibited a positive or negative emotional response.

4.1.4. Coding and analyses

The coding procedure and analyses were identical to those of Experiments 1 and 2. Another researcher coded 25% of sessions, and these two offline coding measures were highly correlated, $r = 0.99$. We again found that differences between the main coder and reliability coder were not biased in the direction of the hypothesis ($M = 0.002$, $t(47) = 0.022$, $p = 0.983$).

4.2. Results

At 10 months, infants' looking patterns mirrored those of Experiment 1, with longer looking to the incongruent emotional reactions, especially following the successfully completed action (Fig. 6). At 8 months, in contrast, infants' looking times did not differentiate between the test events. The ANOVA on looking times revealed no main effect of congruency ($F(1,46) = 0.264$, $p = 0.610$), and a significant congruency $\times$ age group interaction ($F(1,46) = 6.608$, $p = 0.013$). Additional analyses revealed no main effects of any of the counterbalancing factors (familiarization valence order, familiarization start side, test valence order, and test congruence order), and no differences in infants' looking time for the emotion-familiarization trials (Mean (SEM): positive–negative familiarization = 18.54(0.16) s, negative–positive familiarization 18.65(0.19) s).

To clarify the nature of the congruency $\times$ age group interaction, we conducted a separate repeated measures ANOVA for each age group. There was a main effect of congruency in the 10-month-old infants ($F(1,23) = 6.446$, $p = 0.018$), with longer looking to the incongruent trials ($M = 14.315$) than the congruent trials ($M = 11.602$). As in Experiment 1, this effect was driven by an effect of emotional congruence for the completed goal test events ($t(23) = 2.211$, $p = 0.037$) but not for the failed goal test events ($t(23) = 1.148$ $p = 0.263$). However, there was no such effect in the 8-month-old infants ($F(1,23) = 1.676$, $p = 0.208$). In fact, the means were in the opposite direction with slightly longer looking to the congruent reaction ($M = 11.554$) than the incongruent reaction ($M = 9.746$).

To directly compare the effect of congruency in Experiment 1 to the results of the present experiment, we conducted a separate repeated measures ANOVA for each age group with completion (completed goal vs. failed goal) and congruency (congruent vs. incongruent reaction) as within subjects factors and experiment (Experiment 1 vs. Experiment 3) as a between subjects factor. In 10-month-old infants, this analysis revealed a significant effect of congruency ($F(1,54) = 11.005$, $p = .002$) and no congruency $\times$ experiment interaction ($F(1,54) = 0.643$, $p = 0.426$). In contrast, there was no main effect of congruency for the 8-month-old infants ($F(1,54) = 0.232$, $p = 0.632$), but a significant congruency $\times$ experiment interaction ($F(1,54) = 7.69$, $p = 0.008$).

4.3. Discussion

As in Experiment 1, 10-month-old infants showed heightened attention to an emotional reaction that was incongruent with the preceding action context. Again, infants looked longest to a negative emotional reaction when it followed successful completion of a demonstrated goal. In contrast to Experiment 1, however, we found no sensitivity to the incongruent reaction in the younger age group. One explanation of the differing performance of 8-month-old infants in Experiments 1 and 3 is that younger infants more readily understand the goal context in Experiment 1. There, cues such as physical contact between the agent and the barrier, an actual reversal of the agent's trajectory towards the goal, and a failed attempt during the goal familiarization may have made it easier for young infants to understand that the goal persisted even when not attained, and to identify when it had been successfully completed or thwarted. In Experiment 3, the evidence for the goal (or the goal completion) may have been less clear, leading to apparent failure at the younger age. Future research could explore this possibility by directly varying the evidence available for inferring the agent's goal.

5. General discussion

Sensitivity to the congruency between an agent's goal outcome and emotional reaction suggests that 8- and 10-month-old infants relate expressions of affect to their surrounding context. Thus, our findings provide preliminary evidence that preverbal infants are sensitive to the conditions that elicit different emotional reactions, and form expectations about emotional displays based on an analysis of the goals that agents pursue. Furthermore, these experiments raise a number of questions regarding the nature of the representations that support these expectations.

While numerous studies have explored the ability to perceive and learn from others' emotions (see Grossmann, 2010), prior research has left open the possibility that infants understand emotions only as communicative signals

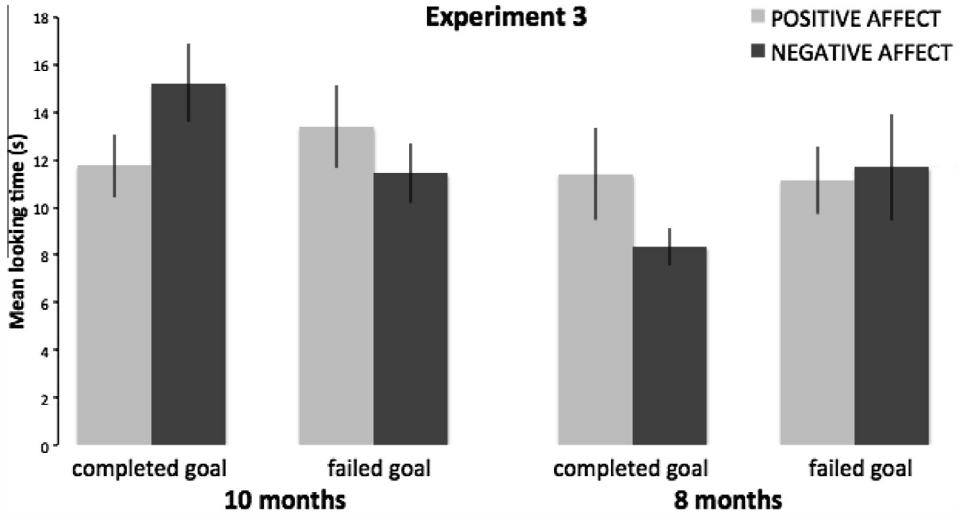

Fig. 6. Experiment 3 results. Mean looking time to test trials in Experiment 3 for each age group. Error bars indicate SEM.

conveying objective properties of the world (i.e. which objects are good and bad). The present findings suggest that infants also understand emotional reactions as relating to idiosyncratic preferences or goals of an agent. One possibility is that infants make emotional predictions that are tailored to agent-specific goals because they construe these emotions as subjective internal states (see also Egyed et al., 2013). However, it is also possible that infants represent these affective expressions as communicative signals reflecting an agent's current needs or goals. For example, negative affect could be seen as a general plea for help, which infants could find surprising in the completed goal trials when no unfulfilled goals are apparent.[3] Investigating whether infants represent emotional displays as social-communicative acts, as overt behaviors that occur in particular contexts, or as manifestations of internal states will be an important topic for future research. Either way, it is notable that across Experiments 1 and 2, infants appear to have different expectations about the very same event, depending on what is known about the agent's goals from its prior actions. When the preceding actions were consistently and efficiently directed towards a goal, infants looked longer if a successful action was accompanied by an incongruent, negative emotion. In contrast, when the preceding actions were not consistently goal-directed or efficient, infants did not differentiate between these events. It appears that infants have not simply associated a specific observable event (e.g. surmounting an obstacle) with a specific affective display, but instead rely on prior knowledge about the agent and its goal.

Nevertheless, these studies leave open the possibility that infants' understanding of actions, goals, and emotions is still developing at 10 months and perhaps undergoes change from 8 to 10 months. For example, there have been conflicting claims as to whether infants this age can infer an agent's goal when a desired result has not been obtained, and whether they have an understanding of failed goals more broadly. To make sense of goal-directed actions, an observer must be able to represent the discrepancy between an agent's current state and a goal state, and thus must, in some sense, represent whether or not a goal state has been achieved. However, this ability may be distinct from understanding that an agent can possess a goal that it is unable to fulfill. To test for this knowledge, Brandone and Wellman (2009) presented 8, 10, and 12-month-old infants with a failed goal condition in which a hand reached with an arched trajectory over a barrier to retrieve a ball but fell short of grasping it, rendering the reach unsuccessful. At test, the barrier was removed and the actor either retrieved the ball directly, or continued to perform the arched reach, which was no longer efficient with respect to the goal object. By 10 months, but not at 8 months, infants looked longer at the inefficient action, suggesting that they encoded the action as directed towards the object even when the agent had not successfully grasped the object during habituation. Based on these results, Brandone and Wellman argued that 8-month-old infants do not construe intentions as internal states that exist independent of the actions taken to fulfill them, and that a more complete understanding of intentions emerges between 8 and 10 months. An alternative interpretation is that 8-month-old infants do understand that goals can be completed or failed, but simply require more information in order to correctly identify an agent's goal in a particular instance. The evidence provided by the failed goal demonstration may have been more ambiguous for infants, such that they identified the goal incorrectly or not at all. Consistent with the latter interpretation, other studies report the ability to infer goals from failed actions in infants younger than 10 months (Hamlin, Newman, & Wynn, 2009).

While emotion attribution may be one way to gain traction on the issue of failed goal understanding, the present results do not clearly distinguish between these possibilities. On the one hand, if an understanding of failed goals is still developing towards the end of the first year, this

[3] Thanks to an anonymous reviewer for pointing out this interpretation.

development might explain the fact that infants exhibit expectations about emotions in the completed goal trials but not the failed goal trials. On this interpretation, when the goal is achieved, infants represent this as a positive state and are surprised by a negative emotional response. In the case of a failed attempt, infants may simply represent the goal as ongoing or as having changed, and therefore fail to differentiate between the positive and negative emotional reaction following this event. However, it is also possible that infants comprehend the failed attempts, but do not map them onto the expected emotions, either because they have yet to learn the relationship between failure and negative emotion, or because both emotions are reasonable responses to this event (see discussion below). Future research might test these interpretations by investigating the development of failed goal understanding more broadly, and by exploring expectations about positive and negative emotions in other emotion-eliciting contexts that do not involve thwarted goal-directed actions.

The present studies are also inconclusive with respect to developmental change between 8 and 10 months. Prior research has yielded conflicting reports regarding the continuity of social cognitive abilities in this age range, and the present findings are similarly ambiguous. Although 10-month-old infants made this distinction across two different action contexts, 8-month-old infants succeeded in only one of these contexts. While it is possible that this finding reflects some change in infants' understanding of emotions, this pattern could also arise from differences in the ease with which infants identify the agent's goal for the two sets of stimuli. Future research should examine the robustness of infants' sensitivity to goal-affect relations at these and other ages.

On the basis of Experiments 1–3, we have argued that infants' attention to the very same emotional display varies based on whether the reaction is congruent with the preceding goal context. However, are there other interpretations of the reported data? One possibility would be that infants have a baseline attentional preference for the negative emotional display (accounting for the longer looking to the negative compared to positive affect in the completed goal condition), and that this general attentional bias is masked by complexity/confusion in the control trials (Experiment 2) and failed goal trials (Experiments 1 and 3). While we cannot rule out this possibility conclusively, we find it to be a less plausible interpretation of the data for several reasons. First, we included a standard control condition (e.g. Csibra et al., 1999; Gergely et al., 1995) in which test events are identical to those shown in the experimental condition, but where the familiarization phase should not be construed as goal-directed. Given that we find no attentional preference in this condition, one would have to argue that the complexity or novelty of these events overwhelms the expression of such a preference. Specifically, although the movements in Experiment 2 are themselves well-matched to the familiarization events in Experiment 1, these actions are less predictable when not goal-directed. While the unpredictable action events could introduce processing demands that mask a baseline attentional bias for negative affect, this explanation does not readily extend to the failed goal events (in which we again observe no difference between positive and negative affect) as these contain coherent, predictable goal-directed action and are no more complex than the successful goal events. In particular, Experiment 3 is very well matched across the failed and completed goal trials, which differ only in the placement of the goal object with respect to the barrier.

One possibility (as discussed above) is that infants do not understand the failed attempt in these trials, and perhaps construe this event as a goal change. However, if this apparent goal change was sufficiently confusing to overwhelm the possible attentional effect, we should find no effect for any conditions in Experiment 1, as all trials include a failed attempt immediately prior to the outcome. Furthermore, if actions in the failed goal trials were confusing or surprising to infants, we might expect heightened attention to both of these events. Instead, we observe very comparable looking time for the failed goal events and the completion event followed by laughter. It is only the event in which the agent exhibits negative affect following goal completion that elicits heightened attention in this study.

However, even if we reject this leanest possibility, there are a number of open alternatives concerning the scope and depth of infant's emotion knowledge. Above, we suggested that infants might form a coherent, generative model of an agent's mind, using behavior to infer an agent's goal, and representing the emotional states that result from achieving or failing to achieve this goal state. On this view, infants represent several key psychological variables (e.g. goals or preferences, emotional states) and the causal laws that relate them. However, a possibility that remains open in the present research is that infants have more directly associated goal completion and failure with overt expressions of affect (either their own or others'), without inferring any sort of internal emotional state. This account still requires that the infant form a representation of the agents' goal, and whether it has been attained. However, on this view, the infant does not posit any internal emotional state, but instead maps the abstract outcome representation onto a perceptual emotion schema directly.

The present research does not distinguish between these alternatives. Indeed, this is a challenge faced by all researchers studying theory of mind in nonverbal creatures (see discussion in Heyes, 1998; Penn & Povinelli, 2007; Perner & Ruffman, 2005; Woodward, 2005), and is not one that we can resolve here. With respect to the specific claims of this paper, however, a relatively lean explanation does seem plausible. If, from early in life, infants represent actions in terms of their goals, and can distinguish events in which an agent's goal state is achieved from events in which it is not, it may be fairly straightforward for infants to learn to associate these outcome variables with the observed facial and vocal expressions of the agents that perform them. Future theoretical and empirical work is needed to distinguish this interpretation from a view in which infants represent a number of causally related internal states in a coherent, theory-like way.

An additional open question concerns the origins of these expectations about emotional reactions. The present results suggest that by 8 months, infants can identify an agent's goal on the basis of observed behavior and form

appropriate expectations about how the agent will then react to completing that goal. However, these results do not bear on the initial origins of these expectations. Infants begin to exhibit sensitivity to others' action goals as early as 3 months (Luo, 2011; Skerry, Carey, & Spelke, 2013; Sommerville, Woodward, & Needham, 2005) and can discriminate different facial expressions starting early in the first year (e.g. Field et al., 1983). One possibility is that as soon as infants encode the goals of observed actions, they represent the affective consequences of completing these goals. Alternatively, infants might start out with a more restricted schema, similar to that proposed by Gergely, Nádasdy, Csibra, and Bíró (1995), and learn over the course of development that failed and completed goals elicit systematically different emotional displays. This learning could take the form described above, where infants map goal outcomes directly onto perceptual representations of emotional displays, or the regularities between outcomes and emotions could support learning over more abstract psychological variables to form theories about the way different mental states interact. The present research cannot distinguish between these possibilities.

Understanding the origins of these expectations might also shed light on the potential asymmetry between failed and completed goals. In the present studies, infants showed violation of expectation to negative affect following a completed goal, but did not distinguish between positive and negative emotion following a failed goal. One explanation, discussed above, is that infants do not have a complete understanding of failed goals. However, this pattern could also be explained in terms of regularities in the input. Humans very rarely exhibit negative affect in response to positive events, but frequently remain neutral, or even laugh, in response to simple failed actions. It seems quite possible, then, that infants receive greater exposure to the correspondence between completed goals and positive emotion than they do the correspondence between failed goals and negative emotions. There is also evidence that, beginning in infancy, humans more readily learn from negative information (see Vaish, Grossmann, & Woodward, 2008). Thus, it is possible that infants simply learn regularities surrounding negative emotions (that they tend to follow failure, not success) more readily than they do those surrounding positive emotions.

A final outstanding question concerns the relevance of early emotion knowledge to infants' understanding of, and engagement in, cooperative or prosocial interactions. A number of studies have found that infants preferentially look at, reach towards, and reward 'helpful' agents over 'hindering' agents: findings that were interpreted as an innate preference for prosocial others (e.g. Hamlin & Wynn, 2011; Hamlin, Wynn, & Bloom, 2007,; Hamlin, Wynn, Bloom, & Mahajan, 2011; Kuhlmeier, Wynn, & Bloom, 2003; but see Scarf, Imuta, Colombo, & Hayne, 2012). Similarly, as soon as they are physically capable, toddlers themselves engage in actions that complete others' instrumental goals, and do so with seemingly little regard to the costs involved or the rewards to be gained (Warneken, Hare, Melis, Hanus, & Tomasello, 2007; Warneken & Tomasello, 2006). A tempting interpretation of these various phenomena is that infants understand the affective value associated with failed and completed goals, and are motivated by the emotional state of the recipient. However, it is unknown whether these preferences and prosocial behaviors are supported by emotion knowledge of the kind investigated here. Given that prosocial behavior is related to empathy and affective perspective-taking in adults (Eisenberg & Fabes, 1990) and young children (Vaish & Warneken, 2012; Vaish et al., 2009), it would be interesting to test whether these earliest prosocial tendencies also rely upon a developing ability to infer emotions from context.

While the present findings raise many unanswered questions, they nonetheless constitute a first step towards characterizing the nature of infants' emotion knowledge, and shed light on the scope of their early goal concepts. Interpreting the behavior of other people in terms of underlying goals or intentions is central to learning from and engaging with others. Beginning in infancy, humans appear to represent others' movements in terms of the goals around which they are structured (Gergely et al., 1995; Woodward, 1998), and these goal representations guide infants' imitation of others (e.g. Gergely, Bekkering, & Király, 2002; Mahajan & Woodward, 2009), and their social interactions (e.g. Behne, Carpenter, Call, & Tomasello, 2005; Warneken & Tomasello, 2006). Here, we provide evidence that infants also form expectations about which affective expressions are likely to follow a successful goal outcome, suggesting that these goal representations may play a relatively flexible role in preverbal infants understanding of others' behavior.

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