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Reaching the goal: Active experience facilitates 8-month-old infants’ prospective analysis of goal-based actions

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ABSTRACT

From early in development, infants view others’ actions as structured by intentions, and this action knowledge may be supported by shared action production/perception systems. Because the motor system is inherently prospective, infants’ understanding of goal-directed actions should support predictions of others’ future actions, yet little is known about the nature and developmental origins of this ability, specifically whether young infants use the goal-directed nature of an action to rapidly predict future social behaviors and whether their action experience influences this ability. Across three conditions, we varied the level of action experience infants engaged in to determine whether motor priming influenced infants’ ability to generate rapid social predictions. Results revealed that young infants accurately generated goal-based visual predictions when they had previously been reaching for objects; however, infants who passively observed a demonstration were less successful. Further analyses showed that engaging the cognitively based prediction system to generate goal-based predictions following motor engagement resulted in slower latencies to predict, suggesting that these smart predictions take more time to deploy. Thus, 8-month-old infants may have motor representations of goal-directed actions, yet this is not sufficient for them to predict others’ actions; rather, their own action experience supports the ability to rapidly implement knowledge to predict future behavior.

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Introduction

Infants learn from the rich interactions they engage in with others, building both their physical and social abilities to become adept social partners. Social interactions play out rapidly in real time, and they often demand not only making sense of one's partner's actions but also doing so prospectively and quickly enough to generate an appropriate verbal or behavioral response. To facilitate the continuation of a successful interaction, social partners must attend to each other's intentions and then deploy their understanding to anticipate and respond quickly to the partner's next actions. For example, if you know that your female friend prefers salty food, then you can use this knowledge to predict that she wants to add salt to her meal. But this knowledge is helpful only if you are able to implement it quickly enough to generate a socially savvy behavioral response (i.e., passing her the salt before she requests it). In contrast, if you anticipate that your friend wants salt only as she is about to grasp the salt shaker, then you have not been a very helpful dinner companion. In this example, the understanding of another person's intentions is equally important as the ability to use this knowledge in real time to generate a prediction. The current study examined the emergence of prospective social reasoning and its relation to infants' own action experience.

The ability to anticipate the outcomes of others' actions emerges early in life. Under some conditions, by 8 months of age infants look ahead to anticipate the endpoint of others' reaching actions, moving their gaze to the target object before the reaching hand makes contact, although this ability becomes more robust later in life (Gredebäck & Melinder, 2010; Henrichs, Elsner, Elsner, Wilkinson, & Gredebäck, 2013; Kanakogi & Itakura, 2010; Kochukhova & Gredebäck, 2010; Paulus, 2011). Infants also show covert shifts in attention in response to observed actions, for example, shifting attention in the direction implied by a still photo of a reaching or pointing hand (Bertenthal, Boyer, & Harding, 2014; Daum, Ulber, & Gredebäck, 2013; Rohlfing, Longo, & Bertenthal, 2012). They also visually predict the outcome of familiar movements with tools, for example, looking to the mouth when seeing a person grasp a cup or to the ear when seeing a person grasp a phone (Hunnius & Bekkering, 2010). Furthermore, by 9 months of age, infants can anticipate the target of a reaching action based on kinematic cues in the hand that correspond to the shape or orientation of the target object (Ambrosini et al., 2013; Filippi & Woodward, 2016). These responses play out at different timescales during online action observation, and they seem to be tuned to human, goal-directed actions (Gredebäck & Daum, 2015; Krogh-Jespersen & Woodward, 2016). Taken together, these findings reveal that infants not only are attentive to the details of others' actions but also are skilled at using the physical information present in an action, including movement trajectory, hand posture, and the presence of tools associated with particular targets, to anticipate action outcomes.

Here we considered infants' ability to recruit another source of information to support action prediction, namely information about a person's prior goals. The actions of a social partner over time can provide information about the partner's goals that can support adaptive predictions about her or his likely next actions. In the previous dinner companion example, if your friend has begun reaching in the direction of the salt shaker, then her motor behavior provides fairly obvious cues regarding her goal. However, if she is opening and closing kitchen cabinets, then this may be more ambiguous as to what the goal of her search is; herein lies the opportunity for you to act on your knowledge of her love for salty food and pass her the salt shaker. Although goal-based predictions can occur in the context of motor and movement cues, they can in principle occur independent of these cues. Goal-based predictions require an analysis of a person's prior actions and the generation of predictions based on the current context, and these cognitive demands are likely to make such predictions particularly challenging for infants (Krogh-Jespersen & Woodward, 2014).

Nevertheless, recent findings indicate that in a simple context infants can make goal-based action predictions by the second postnatal year. For example, Krogh-Jespersen and Woodward (2014) presented 15-month-old infants with video events in which a person grasped one of two objects. Then infants were shown events in which the objects' positions had been reversed and the person began to reach, pausing with her hand midway between the two objects. Infants reliably generated goal-based visual predictions, looking to the object that was the person's prior goal rather than the object in the location to which she had previously reached. In contrast, infants who viewed an ambiguous gesture in which the person touched the object with the back of her hand did not generate systematic goal-based predictions, suggesting that infants were able to quickly identify well-formed, goal-directed actions and respond appropriately to them. In this paradigm, the agent's goal and the trajectory of the movement are dissociated, meaning that infants can only rely on goal information to generate a visual prediction (see Cannon & Woodward, 2012, for similar findings at 11 months of age). Infants' response latencies revealed that goal-based visual predictions took longer to generate than location predictions, suggesting that recruiting an analysis of others' goals is cognitively challenging for infants. Furthermore, the speed with which 20-month-old infants can produce goal-based visual predictions is predictive of their individual competence in an interactive communicative task (Krogh-Jespersen, Liberman, & Woodward, 2015), supporting the conclusion that goal-based predictions are important for social interaction.

In the current experiments, we extended this approach to younger infants to evaluate when the ability to generate goal-based action predictions emerges in development and the factors that may support its emergence. During the first postnatal year, infants have the components of what would be needed to generate goal-based predictions. Visual habituation experiments have indicated that infants encode the goal structure of reaching actions by 6 months of age (e.g., Biro & Leslie, 2007; Feiman, Carey, & Cushman, 2015; Luo & Johnson, 2009; Woodward, 1998, 1999), and as described earlier, infants, visually anticipate reaching movements between 6 to 8 months (Gredebäck & Melinder, 2010; Kanakogi & Itakura, 2010; Kochukhova & Gredebäck, 2010; Rohlfing et al., 2012). When do infants put these two components together? A study by Daum and colleagues suggests that this may be a relatively late achievement (Daum, Attig, Gunawan, Prinz, & Gredebäck, 2012). Within a single paradigm, these researchers evaluated infants' goal sensitivity via their looking times in a visual habituation task, their visual anticipation of a movement trajectory, and their generation of goal-based visual predictions when viewing an animated fish as it moved under an occluder toward a set of objects. They found that 9-month-old infants showed sensitivity to action goals on visual habituation test trials and generated anticipatory saccades to trajectory movements during familiarization trials, suggesting that they were able to encode the relation between an agent and its goal. Nevertheless, infants at this age failed to generate systematic goal-based action predictions during the test trials.

These findings may indicate a hard limit in infants' ability to use goal information to predict actions. In Daum et al.'s (2012) paradigm, reliable goal-based predictions were evident in 3-year-old children but not in 9-, 12-, and 24-month-old infants, and the authors suggested that general cognitive limitations or immaturity of the relevant neural systems may prevent infants from using goal information to generate online action predictions. On the other hand, the findings summarized earlier indicate that under different testing conditions 11- to 15-month-old infants generate goal-based action predictions (Cannon & Woodward, 2012; Krogh-Jespersen & Woodward, 2014). Several factors, including the use of a human agent rather than an animated character, may have made the procedure in these studies more sensitive to the abilities of younger infants. These findings suggest that the capacity to generate goal-based predictions could be in place in infants younger than 11 months and that this ability may emerge in the context of familiar human actions.

As a first test of this possibility, in Study 1 we asked whether 8-month-old infants who view human actions would generate goal-based predictions. To preview the findings, they did not do so, which is surprising given that infants by this age show sensitivity to action–goal structure in less demanding paradigms (e.g., Biro & Leslie, 2007; Woodward, 1999) and typically engage in reaching and grasping actions themselves. In Study 2, we tested whether further increasing infants' familiarity with the focal actions prior to the eye-tracking procedure would support goal-based predictions. We compared the effects of visual experience—watching someone else reach for objects—with the effects of priming infants' own goal-directed actions. Importantly, Study 2 did not attempt to teach a new motor skill as the goal of the intervention was to have infants call to mind their own first-person knowledge of this reaching and grasping action. While visual familiarity alone may provide some support for infants' analysis of the experimental stimuli, we predicted that having infants primed by engaging in their own reaching and grasping actions would be particularly effective in supporting infants' goal-based predictions. Research has shown that active experience can support infants' sensitivity to action goals for the trained action in experiments that do not impose time pressure (Gerson, Mahajan, Sommerville, Matz, & Woodward, 2015; Gerson & Woodward, 2014; Henderson, Wang, Eisenband Matz, & Woodward, 2013; Sommerville, Hildebrand, & Crane, 2008). These effects are stronger for active experience than for conditions in which infants passively observe others' actions. Furthermore, studies have shown relations between infants' motor competence and their visual anticipation of actions based on movement trajectories and motor cues (Ambrosini et al., 2013; Filippi & Woodward, 2016; Gredebäck & Kochukhova, 2010; Kanakogi & Itakura, 2010; Stapel, Hunnius, Meyer, & Bekkering, 2016) and on actions with tools (Green, Li, Lockman, & Gredebäck, 2016; Kochukhova & Gredebäck, 2010). Together, these findings suggest that active engagement could influence infants' propensity to generate goal-based action predictions. We evaluated this possibility in Study 2.

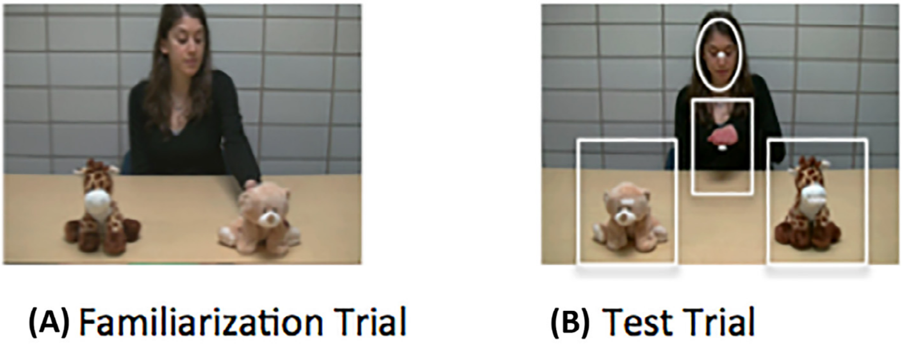
Study 1

In Study 1, we used the paradigm developed by Krogh-Jespersen and Woodward (2014) to test 8-month-old infants (see Fig. 1). Infants viewed a single familiarization trial in which a woman reached for one of two toys, and then they immediately viewed two identical test trials in which the toys' positions were reversed and the woman began to reach, with the video pausing when her hand was midway between the two toys. Using this method, we could first ensure that infants were attentive and responsive to the goal-directed action of an agent during the familiarization event (in which they could generate a visual anticipation based on motor movement/trajectory information) and then ask whether infants could use the information from the familiarization event to generate goal-based predictions on test trials.

Method

Participants

A total of 20 8-month-old infants were included in Study 1 (M_{age} = 7;28 [months; days], range = 7;00–8;14), with equal numbers of boys and girls. All infants were considered full term (minimum 37 weeks gestation). Participants were recruited from an urban population in the United States, and the sample was 50% White, 25% African American, 15% Hispanic, 5% Asian, and 5% multiracial. Given the importance of cumulative gaze information for the data reduction and coding procedures used in the current study, strict criteria for gaze data collection were implemented, leading to an additional 3 infants who were tested but excluded from further analysis due to insufficient data (data collection rate was <50%) from the Tobii eye-tracker ($n = 1$), distress ($n = 1$), or failure to generate a predictive fixation on either test trial ($n = 1$).



(A) Familiarization Trial **(B) Test Trial**

Fig. 1. Still images from the final positions of the experimental stimuli for the familiarization trial (A), which presented movement and trajectory information, and the test trial (B), which did not. Each infant saw one familiarization trial, followed by two identical test trials. Areas of interest are overlaid on the test trial image to represent their locations.

Procedure

Participants viewed videos presented on a 24-in. monitor equipped with a Tobii T60XL corneal reflection eye-tracking system (accuracy of 0.5 degrees and sampling rate of 60 Hz). Infants were seated in their parents' laps at an approximate distance of 65 cm from the monitor. Calibration was performed with a 9-point procedure using the standard animation of a bird provided by the Tobii software within the infant calibration setting. When necessary, the calibration process was repeated to improve accuracy. Data were collected and analyzed using Tobii Studio (Tobii Technology, Stockholm, Sweden). The videos had an audio soundtrack that consisted of a bell sound at the start of the trial and a squeaking sound when the actor completed the reaching and grasping behavior.

All infants saw two pre-familiarization trials, one familiarization trial, and two test trials. The pre-familiarization videos started with an actor demonstrating that she could reach for a single toy (two novel plastic toys for dogs; one per trial) on either side of a table. Next, in a single familiarization trial, she reached for and grasped one of two objects (a stuffed giraffe or bear, as shown in Fig. 1A). The target object (giraffe vs. bear), the hand the actor used (right vs. left), and the side on which the target sat (right vs. left) were counterbalanced. Half of the infants observed a single ipsilateral action during the familiarization trial, and the other half observed a single contralateral action. The timing of the actions was controlled such that the actor looked at the camera (1 s), looked down at her hand (0.5 s), raised her hand (1 s), performed the reaching and grasping action (2.5 s), and held the final resting position (2.5 s). To control for the presence of facial cues during the familiarization trial, the actor looked straight ahead (1 s), looked down to her hand (0.5 s), watched her hand perform the reaching and grasping action (2.5 s), and on contact with the toy looked to the contact point where her hand and the toy were conjoined (2.5 s). During this familiarization trial, infants can rely on movement and trajectory cues from the actor's hand to anticipate the outcome of her action following the initial 2.5 s of the video in which no information is present.

During two identical test trials, the objects were shown in reversed locations from their positions in the familiarization trial, and the actor raised her hand and then paused with her hand centered in mid-air between the two objects (see Fig. 1B). The actor never made contact with either object during the test trials. The timing of the actions in the test trials was as follows: The actor looked at the camera (1 s), looked down at her hand (0.5 s), raised her hand (1 s), and held her hand centered between the two objects (5 s). During the test trials, the actor looked straight ahead (1 s), shifted her gaze down to her hand as she lifted her hand (0.5 s), and then looked at her hand for the remainder of the test trial. She did not look at either object during the test trials. During these trials, infants were not provided with movement and trajectory information; therefore, their visual predictions rely on their ability to recruit and deploy their knowledge of the actor's previous goal-directed action.

Data reduction

Fixation data were extracted from Tobii Studio to calculate where and when infants fixated during the familiarization and test trials using the data tools available in the program, which include calculating total fixation durations to areas of interest (AOIs) and the order in which infants fixated to the relevant AOIs. The AOIs were generated for the actor based on the location of the social information she provided; for example, one AOI encompassed her face and one encompassed the space in which her hand moved during the test trials (i.e., to account for the upward motion).

A total of five static AOIs were created to encompass the female actor's Face and Hand, the Prior Goal and Prior Location objects, and the whole viewing screen (see Fig. 1B). The sizes of the individual AOIs were identical for all counterbalanced versions of the video recordings, and the AOIs did not differ in spatial relationships, allowing for equivalent comparisons of attention. Distribution of infants' attention across the AOIs was calculated using Tobii Studio. The Tobii default fixation filter was used to define fixations; a fixation was defined as a stable gaze (within 0.75 visual degrees) for a minimum of 200 ms. Saccades through an AOI without a fixation within the AOI were not coded as visual predictions. Infants' visual fixations, including their predictive fixations and their attention to the AOIs, were extracted from Tobii Studio.

There were three main measurements for action anticipation, as follows.

Anticipation of the outcome of the reach during the familiarization trial. During the familiarization trial, the actor's hand began reaching to the goal object at 2.5 s and completed the reaching behavior at 5 s (see Fig. 1A). To determine whether infants' fixations to the object were anticipatory or reactionary when movement and trajectory information was present, we computed a difference score from the time that infants' fixated to the goal object minus the time at which the actor's hand overlapped with the object (ranging from 3.60 to 3.88 s). A positive value reflects a reactionary fixation to the goal object, whereas a negative value reflects an anticipatory fixation.

Goal-based predictions during the test trials. During the test trials, the actor paused with her hand centered between the two objects, which had switched positions from the familiarization trial, at the 2.5 s mark and remained in that position for a total of 5 s (see Fig. 1B). Here, a predictive fixation was defined as a fixation to the actor's hand AOI followed by a fixation to either the prior goal AOI (e.g., the object that the actor acted on during the familiarization trial) or the prior location AOI (e.g., the previously unreferenced object). For each trial, infants' visual predictions were coded as either to the prior goal object or the prior location object or as no prediction. The AOIs for the objects were located equally distant from the Hand AOI during the test trials. During these trials, no movement or trajectory information was present. Visual responses were coded by trial, and nonparametric analyses were conducted to analyze the pattern of results.

Goal prediction speed. The latency (in seconds) for infants to generate a prediction during each test trial to either the prior goal object or the prior location was measured from the start of the test trial to the time that a predictive fixation occurred. This latency is referred to as *Goal Prediction Speed* (Krogh-Jespersen et al., 2015), and this measure may reflect the amount of time infants required to recruit information about the actor's goal, relate this information to changes in the context, and then generate a prediction about the actor's future behavior. For each trial, infants' latency to generate a prediction was coded with regard to whether it was toward the prior goal object or the prior location object.

Results

Across all events, the average percentage of usable gaze data (excluding blinks and fixations out of the boundaries of the screen) that was correctly identified by the Tobii eye-tracking system was 81.4% (*SD* = 17.4). In the first analyses, we evaluated infants' ability to visually anticipate the outcome of an agent's reach as her hand was moving toward the objects during the familiarization trial to establish whether 8-month-old infants generate action anticipations when guided by movement and trajectory information. The average difference score (calculated as the latency to fixate the goal object subtracted from the time point at which the actor's hand overlapped with the goal object) was 0.66 s (*SD* = 0.93), with a range from −1.10 to + 2.77. Of the 20 infants, only 3 generated anticipatory fixations to the goal object during the familiarization trial. As such, 8-month-old infants did not systematically visually anticipate the outcomes of the completed actions during the familiarization trial.

Next, we asked whether infants could use their understanding of an actor's actions to generate goal-based predictions. We analyzed infants' visual predictions during the two test trials when the actor did not provide movement and trajectory information regarding the outcome of her actions. Infants generated predictive fixations, looking first to the actor's hand and then to one of the two objects, on 85% of trials. Infants' predictions were equally likely to be to the prior goal and to the object in the location of the prior reach; an exact binomial sign test showed that infants did not systematically generate goal predictions by trial, with infants generating goal-based visual responses on 17 of 34 trials (6 individual trials were excluded from this analysis due to infants' failure to generate a prediction on those trials), $p = .57$. A closer examination of the 4 infants who generated each type of visual prediction (i.e., one goal-based and one location-based visual prediction) reveals that 2 infants generated location-based predictions and 2 infants generated goal-based predictions on test trial 1, thereby not showing a systematic preference for either response on the first test trial. Fig. 2 presents means and standard errors for the proportion of predictive visual fixations to the prior goal or prior location object, and Table 1 presents the nonparametric data.

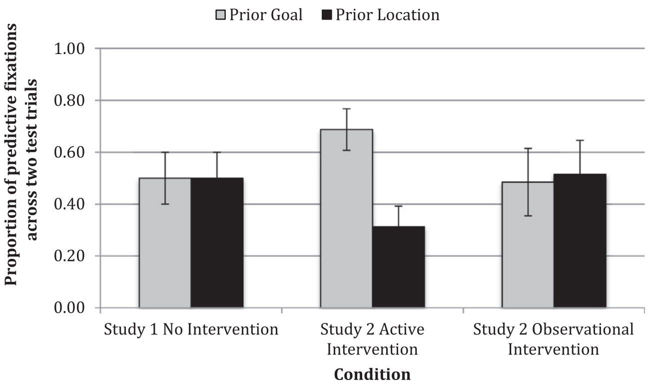


Fig. 2. Proportions of predictive visual fixations to either the prior goal object or the prior location object across Studies 1 and 2.

Finally, we examined infants' Goal Prediction Speed to determine whether infants exhibited a latency difference when generating goal-based versus location-based visual predictions. Infants generated goal-based predictions on average in 2.64 s ($SD = 1.21$) and generated location-based predictions on average in 2.58 s ($SD = 1.48$), $t(32) = 0.13$, $p = .89$. As such, there is no evidence that goal-based predictions, when they occurred, involved a slower processing time. One possibility is that infants may have required more time upon fixating the actor's hand to determine its most likely next action; a latency analysis of whether infants showed differences in the amount of time from the point at which they fixated the hand to the time point at which they generated a fixation that landed on either the goal object ($M = 1.12$ s, $SD = 0.98$) or the location object ($M = 1.17$ s, $SD = 1.04$) did not reveal any differences, $t(32) = 0.13$, $p = .89$. Taken together, these results are consistent with the notion that infants' goal-based visual predictions to either object were generated at random.

Discussion

The results from Study 1 indicate that 8-month-old infants were, as a group, reactionary in their gaze behavior when viewing the outcome of an agent's reaching and grasping action when movement and trajectory information was present, which is inconsistent with some previous research (e.g., Kanakogi & Itakura, 2010). One major difference between our current study and the finding that infants are anticipatory during completed reaching and grasping actions is that our stimuli were filmed to provide a view of the entire agent instead of from an upward angle that provides a view of only the arm reaching and not the agent's body or face. Using a similar angle as the current study, Gredebäck and colleagues found that 10-month-old infants visually tracked reaching actions in a reactionary manner (Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & von Hofsten, 2009). Therefore, these differences in action anticipation results across studies may be due to stimuli presentation.

Although our stimuli are limited for studying action anticipation during the familiarization trial in which movement and trajectory information are present, the test videos do provide a systematic set of conditions for studying whether infants can generate goal predictions based on their ability to recruit their knowledge of the actor's goal. Following the familiarization trial, infants at this age also did not systematically generate goal-based predictions during a more cognitively challenging test in which the absence of movement cues and the change in the goal object's location meant that the only information on which to base a prediction was knowledge of the agent's prior goal. Thus, infants seemed not to recruit an analysis of the agent's goal to generate predictions in this task. These findings converge with those reported by Daum et al. (2012) in 9-month-old infants and indicate limitations in infants' ability to recruit goal information to support online action predictions.

These findings set the stage for testing the factors that support goal prediction in infants and, thereby, shed light on the mechanisms that may be involved in its development. A number of findings indicate correlations between developments in infants' own actions, their visual anticipation of the

Table 1
Nonparametric data for Studies 1 and 2 featuring the number of infants generating visual responses.

	Number of infants who generated goal-based visual predictions	Number of infants who generated location-based visual predictions	Number of infants who generated both types of predictions
Study 1: No Intervention	8	8	4
Study 2: Active Intervention	10	3	7[a]
Study 2: Observational Intervention	6	8	6[b]

[a] A closer examination of the 7 infants who generated both types of predictions reveals that 4 infants generated location-based predictions and 3 infants generated goal-based predictions on Test Trial 1, thereby not showing a systematic preference for either response on the first test trial.

[b] A closer examination of the 6 infants who generated both types of predictions reveals that 3 infants generated location-based predictions and 3 infants generated goal-based predictions on Test Trial 1, thereby not showing a systematic preference for either response on the first test trial.

endpoints of reaching actions (Ambrosini et al., 2013; Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Filippi & Woodward, 2016; Stapel et al., 2016), and actions with tools (Green et al., 2016; Kochukhova & Gredebäck, 2010). One interpretation of these correlational findings is that the cognitive systems that support action control also contribute to the anticipation of others' actions (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Filippi & Woodward, 2016; Flanagan & Johansson, 2003), a hypothesis that is consistent with findings in the adult literature (Costantini, Ambrosini, & Sinigaglia, 2012; Elsner, D'Ausilio, Gredebäck, Falck-Ytter, & Fadiga, 2013; Kilner, Vargas, Duval, Blakemore, & Sirigu, 2004). But these findings leave open the question of the level of cognitive analysis that is involved in this process. It is possible that motor experience could support anticipation based on movement and kinematic cues, but does motor experience also support predictions based on a more abstract analysis of the actor's goal?

One reason to think that it might come from visual habituation experiments that investigate infants' sensitivity to the goal structure of others' actions (e.g., Henderson & Woodward, 2011; Sommerville & Woodward, 2005; Woodward, 1998). Infants' responses in these paradigms correlate with developments in their own actions (Brune & Woodward, 2007; Daum, Prinz, & Aschersleben, 2011; Sommerville & Woodward, 2005). Furthermore, interventions in which infants are provided with motor training, such as the use of "sticky mittens," bolster their sensitivity to others' action goals during a subsequent visual habituation task, whereas passive observational training does not have similar effects (Gerson & Woodward, 2014; Gerson et al., 2015; Henderson et al., 2013; Sommerville et al., 2008). Recent findings using electroencephalogram (EEG) with 4-month-old infants suggest alterations in neural responses when processing others' goal-directed actions following their own experience with active training; similar alterations are not evident following passive training (Bakker, Sommerville, & Gredebäck, 2016). These findings suggest that motor experience supports infants' ability to detect goal structure in observed actions yet leave open the question of whether motor experience supports online goal-based predictions in infants.

Study 2 examined whether action experience supports the goal prediction abilities of 8-month-old infants. The infants in this study experienced an intervention in which they either reached for the objects that appeared in the experimental videos (Active Intervention) or watched as a person sitting next to them reached for the objects (Observational Intervention). By 8 months of age, infants are engaging in reaching and grasping actions themselves. Given that infants have this action in their motor repertoire, one possibility is that they simply require a reminder of the intentionality of the action; if they see a toy that they want, then they can engage their motor system to attain their own goal. If this is the case, then first-person engagement in an action should prime infants to evaluate others' goals as goal-directed; therefore, goal-based visual predictions should be more likely following an active intervention. However, an open possibility is that first-person priming is not necessary given that infants have access to their own knowledge; they might not need to engage their motor system in the action to facilitate the recruitment of their first-person perspective. Infants in the Observational Intervention experience the realness of the toys and an interaction with an experimenter similar to the Active Intervention condition, yet they do not directly engage their own motor system in the reaching and grasping actions. If it is the case that first-person experience is not necessary to facilitate goal-based visual predictions, then we should see improvements in goal-based visual predictions across both interventions. Following their respective interventions, all infants viewed the video series presented in Study 1.

Study 2

Method

Participants

A total of 40 8-month-old infants were included in Study 2 (M_{age} = 7;28, range = 7;00–8;15), with equal numbers of boys and girls. All infants were considered full term. Participants were recruited from an urban population in the United States, and the sample was 50% White, 20% African American, 3% Hispanic, 5% Asian, and 22% multiracial. An additional 6 infants were tested but excluded from further analysis due to insufficient data (data collection rate was <50%) from the Tobii eye-tracker (n = 3), failure to look to both sides of the screen throughout the experiment (n = 1), or failure to generate a predictive fixation on either test trial (n = 2).

Procedure

In this study, infants were randomly assigned to one of two intervention conditions. In the Active Intervention condition, infants sat on their parents' laps directly across a table from an experimenter who placed a series of toys on the table in front of the infants. The experimenter who conducted the interventions was never the woman who appeared as the actor in the video stimuli. The experimenter began by picking one toy located out of sight of the infants and placing the toy directly in front of the infants within reach. Each toy was presented individually, and the experimenter placed the toy on the table while expressing interest in it (i.e., saying "ooooh"). The experimenter began by placing a series of small colorful bath toys (e.g., a pink hippo) individually on the table to encourage infants to reach for the objects. Then infants were given one trial to reach for a stuffed toy that was similarly sized as the target objects but that was not actually presented in the experimental video (i.e., a penguin). This allowed infants to become comfortable reaching for the differently sized objects. Finally, the target objects that served as the prior goal and prior location objects in the experimental videos from Study 1 (i.e., the bear and giraffe) were presented in alternating order such that infants had two opportunities to reach for each of the target objects. The order of whether the first object presented to infants was the object that served as the goal object or the location object in the video stimuli was counterbalanced across participants as well. Infants in the Active Intervention condition were given the opportunity to reach for and grasp all of the objects.

In the Observational Intervention condition, infants were seated directly across from Experimenter 1, who placed the same series of toys on the table as in the Active Intervention condition. However, infants in the Observational Intervention condition were not given the opportunity to reach for and grasp the objects; instead, they observed as Experimenter 2, who was seated to their left, demonstrated the reaching and grasping behaviors with the objects (see Fig. 3). During this intervention, Experimenter 2 maintained attention on the objects and did not engage socially with the infants. Importantly, infants in this condition did not have an opportunity to perform the reaching and grasping actions themselves.

Infants in both intervention conditions viewed the videos from Study 1 immediately following their respective interventions. Data coding and analyses were identical to those in Study 1 for measuring anticipation of the outcome of the reach during the familiarization trial, goal-based predictions during the test trials, and Goal Prediction Speed.

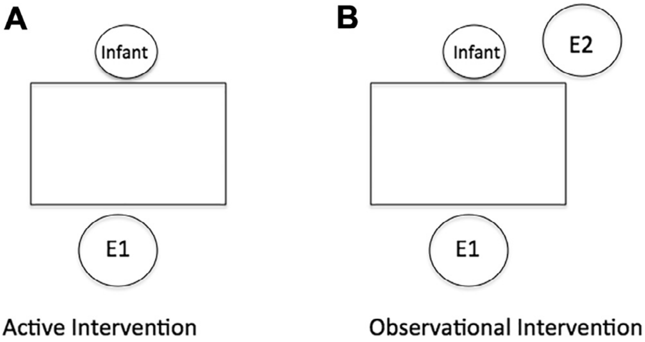


Fig. 3. Schematic of the room setup for Study 2. (A) Active Intervention in which infants were seated directly across from a single experimenter. (B) Observational Intervention in which infants were seated directly across from Experimenter 1 and Experimenter 2 was seated to their left-hand side.

Results

The average percentage of usable gaze data that was correctly identified by the Tobii eye-tracking system did not differ between the intervention conditions (Active: $M = 72.3\%$, $SD = 13.8$; Observational: $M = 70.9\%$, $SD = 14.5$), $t(38) = 0.30$, $p = .77$. As in Study 1, we first examined whether infants generated action anticipations during the familiarization trial of the experimental video stimuli. For the Active Intervention, the average difference score (calculated as the latency to fixate the goal object subtracted from the time point at which the actor's hand overlapped with the goal object) was 0.71 s ($SD = 0.97$), with a range from −0.52 to + 2.77.[1] Of the 20 infants in this condition, 5 generated anticipatory fixations to the goal object during the familiarization trials. For the Observational Intervention, the average difference score was 0.46 s ($SD = 0.75$), with a range from −0.79 to + 2.31. Of the 20 infants in this condition, 4 generated anticipatory fixations to the goal object during the familiarization trials. The two groups did not differ from each other with regard to difference scores, $t(38) = 1.04$, $p = .34$, and neither intervention boosted infants' anticipation of the reaching and grasping action.

The question of interest for Study 2 is whether motor priming supports infants' ability to generate goal-based predictions. Infants generated predictive fixations, looking first to the actor's hand and then to one of the two objects, on 80% of trials in the Active Intervention condition and on 83% of trials in the Observational Intervention condition. An exact binomial sign test showed that infants in the Active Intervention condition systematically generated goal predictions, with infants generating goal responses on 22 of 32 trials, $p = .015$ (see Table 1 for nonparametric data). To our knowledge, this is the first study to find that infants as young as 8 months generate goal-based visual predictions in the absence of sensorimotor information following an active experience opportunity, suggesting that motor engagement may be a supporting mechanism for this ability.

In the Observational Intervention condition, infants did not systematically rely on the goal information to generate visual predictions by trial, with goal responses evident on only 16 of 33 trials, $p = .50$ (see Table 1 for nonparametric data). A Fisher's Exact Probability Test indicated that, although we found a difference from chance with regard to infants' performance in the Active Intervention, the two intervention conditions did not differ from each other, $p = .12$.

One open question is whether infants who succeeded on this task required more time to generate accurate visual predictions. Indeed, infants in the Active Intervention evidenced a latency difference, with goal predictions occurring on average at 3.44 s ($SD = 1.60$), whereas location-based predictions occurred on average at 2.18 s ($SD = 1.45$), $t(30) = 2.11$, $p = .043$, replicating a finding evident from previous research using this task with 15-month-old infants (Krogh-Jespersen & Woodward, 2014). Surprisingly, this latency difference was also present for infants in the Observational Intervention, with

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[1] Latencies for 2 infants in the Active Intervention condition and for 1 infant in the Observational Intervention condition were excluded because the infants did not attend to the hand during the 2.5 s window.

goal-based predictions occurring on average at 3.8 s (*SD* = 0.97) and location-based predictions occurring on average at 2.73 s (*SD* = 1.63), *t*(30) = 2.21, *p* = .035. These latency differences highlight the possibility that infants could be engaging in a more cognitively rich analysis of the actor's goal following both active and passive experience with reaching and grasping actions.

To examine this possibility, we conducted a binomial mixed-effects regression with infants' visual prediction responses (Prior Goal vs. Prior Location), condition (Active Intervention vs. Observational Intervention), and test trial (1 vs. 2) as fixed effects, participant as a random effect, and latency to generate a prediction as the dependent variable to determine whether recruiting goal information imposed a cognitive burden that resulted in longer latencies when generating goal-based visual predictions than when generating location-based predictions. Results revealed that infants' visual prediction response (*B* = −1.16), *t*(62) = −2.91, *p* = .003, was a significant predictor of infants' latency to generate a prediction, with goal-based visual predictions taking longer to generate than location-based visual predictions. Condition (*B* = 0.88), *t*(62) = 2.24, *p* = .03, was also significant in that, overall, infants in the Observational Intervention condition (*M* = 3.34, *SD* = 1.55) took systematically longer to generate a prediction than those in the Active Intervention condition (*M* = 2.69, *SD* = 1.68). Test trial was not a significant factor (*B* = −0.15), *t*(62) = −0.39, *p* = .69. When infants predicted that the actor would continue to act on the goal object, they took longer to produce predictive fixations, regardless of intervention condition, than when they produced simpler location-based predictions.

One possibility is that these latency differences resulted from differences between conditions in the amount of time infants required to fixate to the hand from the start of the trial (i.e., to attend to the information in the test trials prior to meeting the criterion for a fixation to the hand and then the object) to determine its most likely next action. An additional latency analysis was conducted examining the latency from the time point at which infants fixated to the hand to the time point at which they generated a visual prediction; this excluded the amount of time infants may have visually attended to the scene prior to fixating to the hand. Infants in the Active Intervention condition showed no differences in their latency to land on the goal object (*M* = 1.92 s, *SD* = 1.27) or on the location object (*M* = 1.12 s, *SD* = 1.04), *t*(30) = 1.74, *p* = .09. For infants in the Observational Intervention condition, their latency to fixate to the goal object (*M* = 1.67 s, *SD* = 1.17) or to the location object (*M* = 1.10 s, *SD* = 1.09) from the hand was also not significant, *t*(31) = 1.44, *p* = .16. These results suggest that the latency differences are driven by infants attending to the scene prior to fixating to the hand, possibly to update their representations of the unfolding events.

Attentional coding

Additional analyses were conducted to explore whether infants' attention had been entrained differently depending on their condition, because this could influence both the prediction and latency results. For example, one possibility is that longer latencies for goal-based predictions in the Active and Observational Intervention conditions may be due to differences in the extent to which infants in these conditions monitored the relevant regions in each event. Given that the paradigm was identical across Studies 1 and 2, we were able to analyze infants' patterns of attention to the familiarization trial using the AOIs, as discussed in the ''Data Reduction'' section of Study 1. Infants' proportions of attention to the Face, Hand, Prior Goal, and Prior Location AOIs were calculated by dividing their attention to each relevant AOI by their total attention to the whole viewing screen AOI for the familiarization trial. For the single familiarization trial, a repeated-measures analysis of variance (ANOVA) examining the proportions of attention to each AOI (Face, Hand, Prior Goal, Prior Location) revealed that infants' attentional patterns to the AOIs did not differ across conditions, *F*(2, 57) = 0.007, *p* = .99 (see Fig. 4 for means and standard errors).

A one-way ANOVA revealed a trending difference in overall attention during the test trials, *F*(2, 57) = 2.81, *p* = .069, such that infants in the two intervention conditions were equally attentive to the test events (Bonferroni correction, *p* = .84), but both showed overall lower levels of attention during the test trials than infants in Study 1 (Study 1: *M* = 5.81 s, *SD* = 1.58; Study 2 Active Intervention: *M* = 4.84 s, *SD* = 1.45; Study 2 Observational Intervention: *M* = 4.74 s, *SD* = 1.69; Active Intervention vs. Study 1: *p* = .06; Observational Intervention vs. Study 1: *p* = .04). Despite these differences in overall attention levels at test across Studies 1 and 2, the test trial stimuli were identical for the

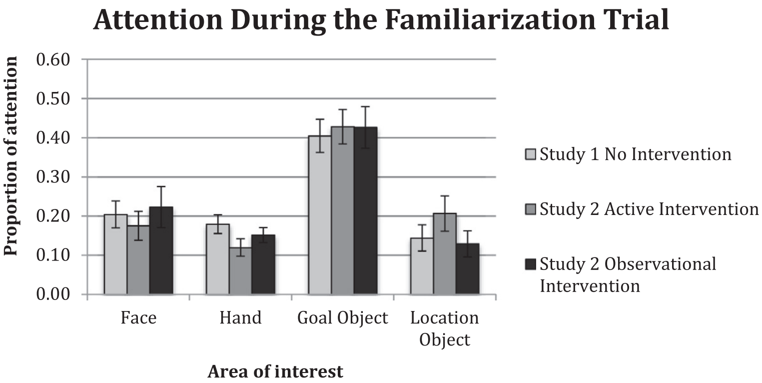

Fig. 4. Means and standard errors for infants' proportions of time spent in each area of interest as a function of their total looking time during the familiarization trial.

two conditions and, as such, low-level properties of these events could not have driven infants' differential predictions across the conditions.

General Discussion

The results from the current set of studies shed light on the development of the ability to think prospectively about others' goal-directed actions. By 8 months of age, infants may have difficulty in using goal information to predict others' future actions. The results of Study 1 revealed that, unlike the 15-month-old infants in Krogh-Jespersen and Woodward's (2014) study, 8-month-old infants do not rapidly recruit their social knowledge to predict the outcome of another individual's goal-directed action. They perform at chance with regard to generating visual predictions, and they do not show a latency difference in terms of Goal Prediction Speed. With no other data, one may conclude that 15-month-old infants have the ability to think prospectively about others' actions, whereas 8-month-old infants do not.

However, the results of Study 2 shed light on the mechanisms that aid in the implementation of infants' knowledge regarding others' intentions or goals. Here, infants in the Active Intervention condition who were provided with the opportunity to activate their motor representations of reaching and grasping actions systematically generated goal-based visual predictions when watching another individual engage in similar motoric actions. These infants also showed the latency difference evident in 15-month-old infants (Krogh-Jespersen & Woodward, 2014), such that goal-based visual predictions took significantly longer to generate than simpler location-based predictions. These findings suggest that action priming helped infants to engage an adaptive but taxing cognitive analysis to generate action predictions. Infants need to recruit and implement their rich cognitive understanding of the actor's goal to visually predict her actions in a new situation (because the objects switched locations at test), which results in longer latencies to generate accurate goal-based predictions.

This latency difference further supports the proposal that younger infants may have difficulty in recruiting their knowledge in real time to predict others' actions. Real-time interactions unfold at a rapid pace, often with opportunities to further the interaction present for only mere seconds. It is during these behavioral interactions that young infants do not appear to be as sophisticated in their social knowledge as they do in more passive experimental paradigms (see Krogh-Jespersen & Woodward, 2016, for a more detailed discussion). The finding that infants require more time to generate a goal-based visual prediction suggests that speed in recruiting and implementing their knowledge may be a limiting factor with regard to infants' social competence, which raises questions regarding how infants become able to more quickly engage in this cognitively challenging process. One possibility is that active experience in young infants may engage a cognitively-based prediction system, which results in slower but potentially smarter visual anticipations of others' goal-directed actions. Herein lies one interpretation of the longer latencies evident for the infants in the Observational Intervention condition as they did not systematically generate goal-based predictions: The Observational Intervention may have stimulated this rich cognitive analysis of the goal-directed actions yet did not fully support the implementation of this knowledge in a rapidly unfolding eye-tracking task. The lack of a difference in the generation of goal predictions between intervention conditions suggests that this stimulation is fragile and may require more experience across different contexts to strengthen.

At 8 months of age, infants are skilled at producing reaching and grasping actions themselves and are successful when reasoning about others' reaching and grasping actions when motor information is provided, such as when stimuli are presented such that the moment when the actor's hand and object overlap occurs over a longer time period (e.g., Kanakogi & Itakura, 2010), and in visual habituation studies, when the actor successfully attains her or his goal (Brandone & Wellman, 2009). As such, this may be an age when visual experience primes existing knowledge regarding goal-directed actions yet does not fully facilitate the implementation of this knowledge to generate a correct prediction. Our current results do not allow us to address the question of what is driving the latency and accuracy results; as such, future research should focus on examining the conditions through which this cognitive-based prediction system is enriched.

Embodied cognition accounts generally argue that we activate our own motor plans when engaging in an action ourselves but that we experience the same motor system activation when observing another person engage in the same action (Flanagan & Johansson, 2003). This motor system activation may generate a matching of our own actions with those produced by others, leading us to generate visual predictions for others' behavior as we do for our own (Costantini, Ambrosini, Cardellicchio, & Sinigaglia, 2013; Elsner et al., 2013; Gredebäck & Falck-Ytter, 2015). In these accounts, action prediction is a result of motor system activation, suggesting that infants in our study who were given the opportunity to reach for and grasp the object themselves may have experienced the motor system activation necessary to generate predictive goal-based visual responses. An alternative account by Southgate (2013) suggested that infants first need to identify the goal and then recruit their motor system to simulate the movements required to attain that goal. Infants who are familiar with the action, as the 8-month-old infants in our study should have been with the reaching and grasping actions, can recruit their motor system to visually predict the most likely outcome of that action. The current study does not provide a means to distinguish between these accounts; however, the relationship between motor system engagement and predictive reasoning abilities is one area of relevance for future research.

Moreover, our results shed light on two different processes that may be engaged when infants are perceiving social actions. One is a "bottom-up" sensorimotor process that relies on motor system representations of the action being performed. This system appears to be fairly sophisticated in young infants who can rely, under specific circumstances, on movement and trajectory information to anticipate the outcome of familiar actions. A second process relies on "top-down" knowledge about others' intentional natures that, once activated, allows infants to generate predictions regarding others' goal-directed actions even in novel situations without the presence of sensorimotor information (see Yu & Smith, 2016, for a similar proposal regarding joint attention). Further research is needed to distinguish how these two processes are activated in young infants and to explore how engagement in motor activity influences social knowledge.

It has been hypothesized that action knowledge is supported, to some extent, by shared action–production/perception systems. Given that the motor system is inherently prospective, infants' understanding of goal-directed actions should support *predictions* of others' actions (Falck-Ytter et al., 2006; see also Flanagan & Johansson, 2003). Consistent with this possibility, the results from this set of studies show that 8-month-old infants engage their analysis of others' goal-directed actions to generate goal-based predictions when their motor representations have been engaged. In a challenging task, active experience with the relevant action facilitated infants' recruitment of their understanding of others' actions when predicting future behavior. The current findings lend support to the conclusion that the systems for producing (i.e., motor) and perceiving (i.e., cognitive) goal-directed action develop together early during the first year of life. Thus, as infants reach for the goal themselves, they are better able to predict what others will do next.

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