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During the first year of life, infants possess some of the key social–cognitive abilities required for success in a social world: Infants interpret others' actions in terms of their intentions and can use this understanding prospectively to generate predictions about others' behavior. Exactly how these foundational abilities develop is currently unknown. The goal of this study was to shed light on the developmental mechanisms underlying changes in infants' understanding of intentional actions by documenting relations between infants' intention understanding and other emerging social (joint attention) and motor (means–end and self-locomotion) abilities. Using eye tracking, 8- to 11-month-olds infants' ($N = 80$) ability to visually predict the goal of an ongoing successful or failed intentional action was examined in relation to their developing means–end, self-locomotion, and joint attention abilities. Results confirmed previous findings showing improvements in infants' ability to interpret and make predictions about others' failed intentional actions. Importantly, results also indicated that parent-report measures of infants' initiating-joint-attention and self-locomotion abilities were associated with the ability to visually predict the outcome of a failed reaching action. These data support the view that infants' social and motor experiences may contribute to changes in their social–cognitive abilities. In particular, joint-attentive social interactions that occur with increasing frequency as infants learn to crawl and walk may shape infants' understanding of others as intentional agents.

Keywords: intention understanding, social cognition, infant development, joint attention, crawling

Success in a social world depends on the ability to understand, predict, and learn from the actions of others. During the first year of life, infants possess some of these key social–cognitive abilities (for a review, see Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009). Infants interpret others' actions in terms of their underlying intentions (Brandone & Wellman, 2009; Gergely, Nádasdy, Csibra, & Bíró, 1995; Woodward, 1998) and use this understanding to guide their social interactions (Behne, Carpenter, Call, & Tomasello, 2005; Warneken & Tomasello, 2006). These early abilities are an important precursor to more sophisticated mental state reasoning (Aschersleben, Hofer, & Jovanovic, 2008; Wellman & Brandone, 2009; Wellman, Lopez-Duran, LaBounty, & Hamilton, 2008) and are crucial for subsequent social, cognitive, and linguistic development (Baldwin & Moses, 2001; Csibra & Gergely, 2007; Tomasello, 1999).

A key question for developmental psychologists is how these foundational abilities develop. Although some interpret infants' early competence as evidence of an innate psychological reasoning system that exists independent of experience (e.g., Bíró & Leslie, 2007; Gergely & Csibra, 2003; Luo & Baillargeon, 2005), other accounts point to learning and experience as the mechanisms underlying the development of social–cognitive knowledge (e.g., Barresi & Moore, 1996; Moore, 2006; Tomasello, 1995; Woodward, 2009). The goal of this article is to explore how the rich information provided in infants' social and motor experience may contribute to their developing understanding of intentional actions.

Infants' Understanding of Intentional Actions

The ability to read past the surface appearance of actions and make inferences about the subjective internal states (i.e., intentions) that structure them appears early in infancy. In the first year, infants are sensitive to the intentional structure of human behavior and readily interpret others' actions as rational and goal directed (Baldwin, Baird, Saylor, & Clark, 2001; Brandone & Wellman, 2009; Gergely et al., 1995; Woodward, 1998). Eye-tracking data

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suggest that infants also use their understanding of human behavior prospectively to generate rapid online predictions about an agent's intentional actions as they unfold over time (Brandone, Horwitz, Aslin, & Wellman, 2014; Cannon & Woodward, 2012; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Gredebäck & Melinder, 2010; Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & von Hofsten, 2009; Hunnius & Bekkering, 2010; Kanakogi & Itakura, 2011; Kochukhova & Gredebäck, 2010). This prospective understanding of human behavior is crucial for interpreting social situations and interacting seamlessly with others.

In recent years, an increasing number of researchers have begun to use *failed* action understanding as a test of infants' social–cognitive abilities. Reasoning about the goal of a failed action provides a strong test of intention understanding, because the observed pattern of motion is distinct from the intention in a failed action (Meltzoff, 1995). Unlike successful actions, in which the goal is apparent in the achieved outcome (e.g., reaching for and successfully grasping a goal object), in failed actions (e.g., reaching for but failing to grasp a goal object), the actor's goal is unrealized and, thus, not apparent in the action itself. Therefore, to understand a failed action appropriately, infants must be able to differentiate the observed action and outcome from the unobserved internal state that motivates it.

Several recent studies have demonstrated that infants indeed interpret failed actions in terms of these actions' unseen goals (Behne et al., 2005; Brandone et al., 2014; Brandone & Wellman, 2009; Daum, Prinz, & Aschersleben, 2008; Hamlin, Hallinan, & Woodward, 2008; Hamlin, Newman, & Wynn, 2009; Legerstee & Markova, 2008). For example, in Brandone and Wellman (2009), infants were habituated to an actor reaching over a barrier to retrieve a ball. In some conditions, the actor successfully retrieved the ball; in others, he narrowly missed the ball and failed to retrieve it (see Figure 1). Following habituation, all infants saw test events where the barrier was absent, and the actor successfully retrieved the ball. In direct-reach test events, the actor followed a rational and efficient path and reached directly for the ball; in indirect-reach test events, the actor used the same arcing reach as in habituation. If infants interpreted the habituation action in terms of its underlying intention (getting the object as directly as possible), then during test events, they should have looked longer at the event that was inconsistent with that goal—the indirect event. Results confirmed that infants as young as 8 months understood the successful action: They looked longer at the indirect- than at the direct-reach test event. In contrast, only 10- and 12-month-olds showed understanding of the more complex failed reach. Eight-month-olds looked equally at both events.

Similar age effects emerged when examining infants' ability to generate rapid online predictions about the goals of these successful and failed reaching actions using eye tracking (Brandone et al., 2014). Ten-month-olds were able to predict the goal of an intentional reaching action (as demonstrated by an anticipatory look to the goal object), even when the action was unsuccessful and the actor repeatedly failed to achieve his goal. In contrast, 8-month-olds showed predictive looks to the outcome of a successful reaching action only. When the actor failed to achieve his goal, 8-month-olds tracked the actor's failed reach in a more reactive manner—looking at the intended goal much later and sometimes not at all. These eye-tracking data also revealed developmental differences in infants' ability to revise their predictions about others' intentional actions in response to accumulating evidence. Like adults, 10-month-olds (but not 8-month-olds) showed evidence of sensibly modifying their looking patterns in the failed reaching condition when their initial goal predictions were not confirmed. That is, although they produced anticipatory looks to the intended outcome of the failed action early in the experiment (i.e., during the first triad of trials), 10-month-olds also responded flexibly to mounting evidence of the actor's failure later in the experiment by fixating less and less on the ball over time (i.e., in the second and third triads of trials).

The pattern of results across these studies indicates that infants' ability to understand and make predictions about others' intentional actions undergoes important changes late in the first year. Although the ability to infer an actor's goal while or after observing the actor achieve it (e.g., successfully grasping and retrieving

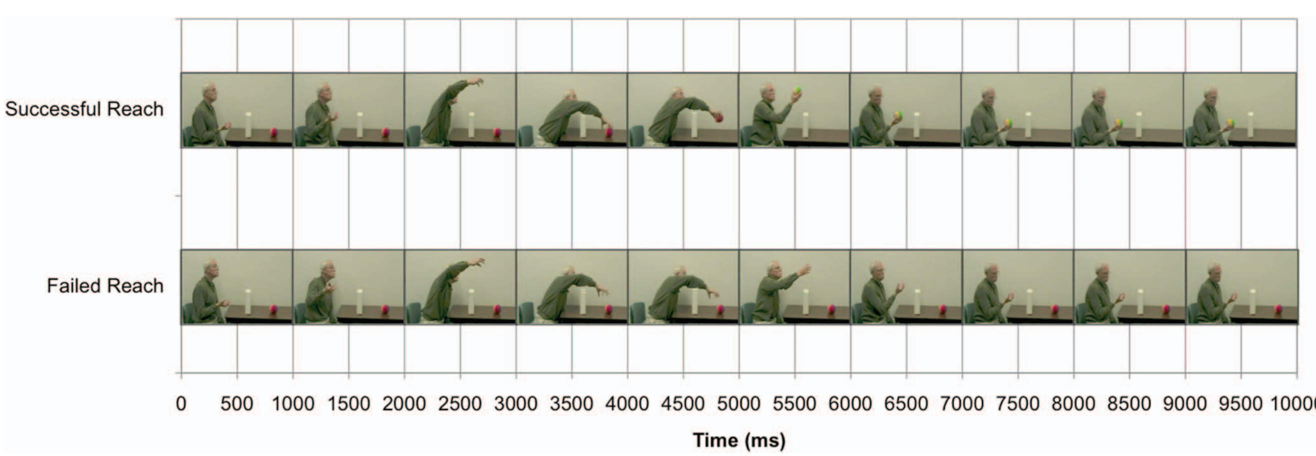

Figure 1. Time course depiction of the successful and failed reaching events. Adapted with permission from "Infants' Goal Anticipation During Failed and Successful Reaching Actions" by A. C. Brandone, S. R. Horwitz, R. N. Aslin, and H. M. Wellman, 2014, *Developmental Science, 17,* p. 25. Copyright 2013 by John Wiley & Sons. See the online article for the color version of this figure.

a ball) is present early, the more robust ability to interpret, make predictions about, and respond flexibly to more complex actions in the absence of outcome information undergoes further development. These results are consistent with the view that infants' initial understandings of human action may capture regularities of behavior observed through experience (e.g., that actions are directed toward objects and are rational and efficient; Gergely et al., 1995; Woodward, 1998). However, it is not until later in the first year that infants move beyond this basic understanding and begin to view human behavior as motivated by subjective internal states (i.e., intentions).

A key question arising from these results concerns the mechanisms by which infants' understanding of intentional human behavior develops. To explore this question, in the current study, I examined how experiences infants encounter in their daily lives may contribute to changes in intention understanding late in the first year.

Mechanisms of Change in Intention Understanding

The literature on the development of infant social cognition highlights two kinds of experience as important potential influences on infants' emerging understanding of intentional action. First, many researchers have argued that infants' own experience as intentional agents influences their understanding of others' actions (e.g., Daum, Prinz, & Aschersleben, 2011; Gallese, Rochat, Cossu, & Sinigaglia, 2009; Meltzoff, 2007; Tomasello, 1999; Woodward et al., 2009). On this view, infants' ability to structure their own goal-directed actions enables them to see intentional structure in the actions of others. Support for this proposal comes from research indicating systematic relations between the actions infants can produce and the actions they can interpret in others. For example, at 5–6 months, the age at which infants begin to make skilled intentional grasps, infants also begin to understand others' grasps as goal directed (Woodward, 1998). Further evidence comes from experimental manipulations that alter infants' action capacities and observe the effects of those changes on their perceptions of others' actions. For example, when 3-month-olds (who are not yet skilled in producing goal-directed grasps and who do not understand others' grasps as goal directed) gained experience manipulating the movement of toys using Velcro mittens, they later interpreted an experimenter's object-directed reaches as goal directed (Sommerville, Woodward, & Needham, 2005). These results support the conclusion that infants' first-person agentive experiences provide them with particularly strong insights into others' actions (see also Gerson & Woodward, 2014; Meltzoff & Brooks, 2008; Skerry, Carey, & Spelke, 2013).

To date, the effect of first-person agentive experience has generally been evaluated by examining the experience of producing a specific goal-directed action (e.g., reaching) and its influence on interpreting that specific action in others. However, there are additional ways to think about the effects of first-person action experience on infants' views of others' actions. For example, Skerry et al. (2013) showed that 3-month-olds can generalize information learned from experience manipulating objects using Velcro mittens to kinematically distinct actions (e.g., reaching over a barrier when no barrier was present during training), casting doubt on the idea that a motor representation of a specific action (derived through first-person experience producing that specific action) is required for understanding that action.

Here, I consider another distinct yet related possibility—namely, that other aspects of the experience as an intentional agent also influence infants' views of others' intentionality. In the second half of the first year, infants' begin to behave in other ways that are clearly intentional and could provide first-hand experience of intentionality. For example, the ability to produce means–end actions—actions that involve the deliberate execution of a sequence of steps to achieve a goal (e.g., removing a cover to search for a hidden object)—appears late in the first year. This skill has been argued to serve as an indicator of infants' own intentionality and the ability to mentally differentiate the goal of an action and the means required to achieve it (Piaget, 1953; Willatts, 1999). Given that intention understanding requires a similar kind of distinction between action (i.e., means) and intention (i.e., end), first-hand experience producing means–end actions may provide an important source of input to infants' developing intention understanding.

Around the same time that they begin to engage in means–end actions, infants also gain the ability to locomote independently (i.e., crawl), granting them a new level of autonomy to act on their own intentions (Campos et al., 2000). This capacity coincides with the onset of several other cognitive and emotional skills and has been argued to dramatically change the way infants interact with their physical and social world (Bai & Bertenthal, 1992; Campos et al., 2000; Herbert, Gross, & Hayne, 2007; Higgins, Campos, & Kermoian, 1996; Cicchino & Rakison, 2008). As Campos et al. (2000) noted, "Crawling creates many new goals and enables the attainment and frustration of many others" (p. 157). For example, following the onset of crawling, infants can move independently to a desired object or person and can also be thwarted in their attempts to do so. Thus, it may be that infants' experience of self-locomotion provides a powerful type of first-hand agentive experience that leads to broad insights about both their own and others' intentionality. One goal of the current study was to examine the potential relationship between these broader motor experiences of intentionality and changes in infants' understanding of others.

Infants' ability to produce their own intentional actions is likely only one part of a larger set of experiences that promotes infants' social cognition. A second type of experience that has been argued to play a role in infants' emerging understanding of intention is experience acting in coordination with social partners, in particular in joint-attentive interactions (Barresi & Moore, 1996; Bretherton, 1991; Carpenter, Nagell, & Tomasello, 1998; Tomasello, 1999). Joint attention involves sharing attention with others and consists of behaviors that include responding to others' attention (e.g., following the direction of another's gaze) and actively directing the attention of others (e.g., pointing to direct others' attention; Mundy et al., 2007). Although some have argued that the ability to participate in joint attention *reflects* intention understanding on the part of infants (e.g., Bretherton, 1991; Bruner, 1983; Tomasello, 1999), others have proposed that infants *use* joint-attentive interactions to gain insight into the intentionality of others (Barresi & Moore, 1996; Moore, 2006; Mundy & Newell, 2007). On the latter view, as infants share attention, action, or emotion with others, their intentions become aligned with those of their interactive partners. According to Moore and colleagues (Barresi & Moore, 1996; Moore, 2006), this experience offers infants a special opportunity to integrate first- and third-person information and, thus, construct a representation of others' intentionality.

Although individual differences in joint attention abilities among infants have been shown to be related to variability in subsequent language and cognitive development (e.g., Mundy & Gomes, 1998; Tomasello & Todd, 1983), little research has tested the association between joint attention abilities and an understanding of intention (for an exception, see Brune & Woodward, 2007). Given that changes in the ability to engage in joint attention occur during the first year (e.g., Carpenter et al., 1998; Striano, Stahl, & Cleveland, 2009), these experiences may well contribute to changes in infants' intention understanding. Thus, a second goal of the current study was to examine the relationship between infants' joint attention experience and their understanding of others' intentional actions.

Finally, when considering the influence of both motor and social experiences on developing social cognition, an intriguing additional possibility is that these experiences interact to shape infants' intention understanding. In particular, self-locomotion has been shown to change the nature of infants' interactions with social partners. Crawling infants spend more time in interactive play games and in distal communicative interactions with their mothers than do noncrawling infants (Campos et al., 2000; Campos & Stenberg, 1981). Crawling has also been shown to influence the development of responses to joint attention, with crawling infants (and infants given artificial locomotor experience; Gustafson, 1984) showing greater skill in following the gaze and gestures of others (see also Clearfield, 2011). These findings raise the intriguing yet untested possibility that self-locomotion contributes to an emerging understanding of intention by altering infants' experiences with those around them and inviting opportunities for joint-attentive social interactions. A third goal of the current study was to test this mediational model of the relationship between motor abilities, joint attention, and intention understanding.

In sum, the existing literature on the development of intention understanding shows that infants begin to read past the surface features of actions and make inferences about agents' intentions during the first year of life. However, considerably less is known about how and why changes in this ability occur. In particular, it remains an open question whether infants' ability to predict the goal of an ongoing intentional action is related to their developing means–end, self-locomotion, and joint attention abilities. By exploring which social and motor behaviors are related to individual differences in intention understanding, the current study aimed to provide insight into potential mechanisms through which an understanding of intention develops late in the first year.

The Current Study

The current study explored the association between 8- to 11-month-olds' ability to interpret and make predictions about successful versus failed intentional actions and their emerging social and motor abilities. I was particularly interested in the associations between infants' social and motor experience and their understanding of *failed* intentional actions because (a) actions in which the observed patterns of motion are distinct from their intentions have been argued to provide a more robust test of an intentional understanding of human behavior than actions that successfully achieve their goals, and (b) infants' ability to understand and make predictions about others' failed (but not their successful) intentional actions has been shown to undergo important changes between 8 and 11 months of age (Brandone et al., 2014; Brandone & Wellman, 2009).

As in Brandone et al. (2014), this study examined infants' ability to anticipate the goals of ongoing successful and failed intentional actions using eye tracking. Participants were shown videos of a person reaching in an arcing motion over a barrier for a ball and either successfully or unsuccessfully retrieving it. The measure of interest was infants' ability to predict the goal of the reaching actions, as demonstrated by anticipatory looks to the ball. Patterns of anticipatory looking during initial trials were of focal interest given that prior work revealed age effects during early trials. Changes in those patterns in response to accumulating evidence of the actor's failure were also examined.

Importantly, infants' performance on the eye-tracking task was also examined in relation to their emerging social and motor skills. To assess these abilities, parents were asked to answer questions about their infants' self-locomotion, means–end actions, and joint attention abilities. Parental questionnaires were selected for this initial exploratory study for two main reasons: (a) because questionnaires provide an efficient way to examine a broad range of potentially influential experiences, and (b) because parents can be especially apt observers of infant behavior. Parents are in a unique position to observe their child in a variety of settings, note infrequent but important accomplishments, and aggregate scattered observations into more coherent assessments.

The following predictions were made. First, I predicted that anticipatory looking results would replicate those reported in Brandone et al. (2014). Namely, age differences in the likelihood of producing an anticipatory look to the ball were predicted to appear in the failed but not the successful reaching condition, and these differences were expected to be concentrated in early trials—before more advanced infants adjusted their expectations in response to the actor's repeated failure. Second, I predicted that variability in scores on the parent-report questionnaire would be related to variability in performance on the eye-tracking task. Specifically, participants with more advanced joint attention, self-locomotion, and means–end action scores were predicted to show more anticipatory looks to the ball during initial trials of the reaching events. Third, joint attention abilities were predicted to mediate the relationship between self-locomotion and performance on the eye-tracking task. Finally, I predicted that these associations would be stronger for participants in the failed reaching condition because interpreting a failed action provides a more robust test of an understanding of intention.

Method

Participants

Eighty infants between 8 and 11 months of age participated. Eye-tracking data from a subset of these infants ($n = 48$) were also reported in Brandone et al. (2014). Infants were randomly assigned to the successful ($n = 40$; $M = 9.51$ months, $SD = 0.97$) or the failed reaching condition ($n = 40$; $M = 9.48$ months, $SD = 0.98$).

An additional 13 infants were excluded due to fussiness ($n = 3$), poor eye-tracking signal ($n = 1$), failure to calibrate ($n = 3$) or meet inclusion criteria (described later; $n = 4$), experimenter error ($n = 1$), and parental distraction ($n = 1$). Participants were predominantly European American and from middle-income homes.

Procedure and Measures

During a single laboratory visit, infants completed an eye-tracking measure of their ability to make predictions about ongoing successful or failed intentional actions. Parents completed a questionnaire designed to assess variability in infants' motor and joint attention skills.

Eye-Tracking Task

Apparatus. Gaze data were collected in two laboratories using different Tobii eye trackers (Tobii Technology, Stockholm, Sweden): a 17-in. 1750 (ns = 26 and 22 for the successful and failed conditions, respectively) and a 24-in. T60XL (ns = 14 and 18 for the successful and failed conditions, respectively). Tobii eye trackers measure where infants are looking as they watch stimulus videos using a corneal reflection technique. Data rates for the Tobii 1750 and T60XL are 50 Hz and 60 Hz, respectively. Both systems have mean accuracies in the range of 0.5–1.0 visual degree, and both introduce slight delays (verified at 50–100 ms). Data did not differ as a result of which eye tracker was used ($ps > .43$).

Stimuli and procedure. During the eye-tracking task, infants sat on a parent's lap or in a high chair approximately 60 cm from the eye-tracker screen. Participants saw one of two reaching events identical to those in Brandone and Wellman (2009) and Brandone et al. (2014; see Figure 1). Events began with a 1,000-ms sequence in which an actor gazed over a barrier at a ball. In the *successful reaching* event, the actor then reached in an arcing motion over the barrier, grasped the ball, and brought it back to his torso, and the video froze. In the *failed reaching* event, the actor reached in an arcing motion over the barrier but narrowly missed the ball. After hovering momentarily with his hand separated from the ball, the actor brought his empty hand back to his torso, and the video froze. Both actions totaled 6,000 ms in duration, followed by a 3,000-ms freeze (selected so that the total duration of the trials would be comparable to infants' average duration of looking during the habituation version of this task; Brandone & Wellman, 2009). Participants were presented with 10 repetitions of either the successful or the failed reaching event. Reaching events alternated with a brief animation designed to center participants' attention on the screen.

Data processing. Gaze data processing was performed using custom-made analysis programs in Matlab (Mathworks Inc., Natick, MA). Trials on which a participant watched the full screen for less than 50% of the reaching action were excluded from the data. Across participants, 4.2% of trials were dropped for this reason. The number of trials dropped per participant did not differ by condition. Participants for whom five or more trials were dropped were excluded from the final data ($n = 4$). On the remaining trials, gaze shifts to the ball were analyzed. A circular area of interest (AOI) was defined manually around the ball. The AOI subtended approximately 1° beyond the outer limit of the ball. This buffer was selected on the basis of previous work (Brandone et al., 2014), standards in the field (see Gredebäck, Johnson, & von Hofsten, 2009), and estimates of inaccuracies in the Tobii systems (0.5°–1.0°).

Central analyses examined whether participants' gaze shifts to the ball were anticipatory. Anticipatory looks are typically defined as gaze shifts to the goal of the action before the action is completed (e.g., Falck-Ytter et al., 2006). However, because the failed action is never technically completed, an alternative definition was needed. As in Brandone et al. (2014), I defined anticipatory looks using a criterion that involves a distance between the hand and the ball. The benefit of a distance criterion is that it can be applied equally to the successful and failed reaching events and, thus, can be equated across conditions. A distance of 2° was selected because 2° is the distance between the actor's hand and the ball at the full extension of the failed reach, thus representing the smallest distance between the ball and the hand that applies to both conditions. *Anticipatory looks* were thus defined as any fixations to the AOI that occurred before the actor's hand was 2° away from the ball.

Parent Questionnaire

Parents of the infant participants completed an 18-item questionnaire designed to provide a measure of motor and social behaviors hypothesized to be related to intention understanding. The goal was to investigate how variability in infant behaviors is related to variability in understanding intentional actions (as revealed in the eye-tracking task). For all items, parents were instructed to indicate whether their child performs the behavior "often," "sometimes," or "not yet." Two points were given for behaviors that occurred often, one point for behaviors that occurred sometimes, and no points for behaviors that had not yet occurred.

Self-locomotion. Four items assessed infants' self-locomotive development (see Table 1). Self-locomotion scores were calculated by summing parents' responses to these four items. Total self-locomotion scores ranged from 0, for infants who were not yet self-locomoting, to 8, for infants who were walking independently ($M = 4.18$, $SD = 2.10$). Scores between 0 and 8 indicate some self-locomotion abilities (crawling, pulling to a standing position, and/or walking with support). There were no differences in the self-locomotion abilities of infants assigned to the successful and failed reaching conditions, $t(78) = 0.74$, $p = .46$.

Means–end behavior. Two items were designed to assess infants' ability to produce behaviors that involve the deliberate execution of a sequence of steps to achieve a goal. Because all parents responded affirmatively to one item ("Does your child reach for objects that are out of reach?"), this item was dropped from further analyses, and only a single item was used as a measure of means–end ability (see Table 1). Scores ranged from 0 to 2 ($M = 1.53$, $SD = 0.60$) and did not differ by condition, $t(77) = -0.65$, $p = .52$.

Joint attention. Twelve items assessed behaviors related to joint attention. Nine were taken or modified from the Modified Checklist for Autism in Toddlers (Robins, Fein, & Barton, 1999), an instrument designed to assess risk for autism spectrum disorders. Because the infants tested here were considerably younger than the toddlers this instrument was designed for, variability on

Table 1
Behaviors Assessed in the Parent Questionnaire (and Factor Loadings for the Final Seven Joint Attention Items)

Factor	Behavior (and factor loading)
Self-locomotion	Crawling
	Pulling up to a standing position
	Walking with support
	Walking independently
Means–end abilities	Searching for objects that are covered or partially hidden
Initiating joint attention	Pointing to request something[a] (.86)
	Pointing to show interest in something[a] (.85)
	Showing objects of interest by holding them up or approaching with them[a] (.55)
	Offering objects of interest[b] (.53)
Responding to joint attention	Following a point to something across the room[a] (.52)
	Following a look to something across the room[b] (.89)
	Sharing visual attention to objects[a] (.50)
Eliminated joint attention items	Engaging in imitation[a]
	Orienting to one's own name[a]
	Attempting to draw others' attention to one's own activity[a]
	Engaging in social referencing[a]
	Looking back and forth between a play partner and an object during play

[a] Taken from the Modified Checklist for Autism in Toddlers (see Robins, Fein, & Barton, 1999, for precise item wording). [b] Taken from the Communication and Symbolic Behavior Scales Development Profile Infant–Toddler Checklist (see Wetherby & Prizant, 2002, for precise item wording)

the selected items was expected to reflect normative differences in the development of joint attention. Two additional joint attention items were taken from the Communication and Symbolic Behavior Scales Development Profile Infant–Toddler Checklist (Wetherby & Prizant, 2002), and one item was created for this study on the basis of the literature on joint attention (Carpenter et al., 1998).

A factor analysis was conducted to evaluate patterns among the joint attention items and assess whether they could be explained in terms of a reduced number of variables. Following preliminary analysis, four items were eliminated due to weak correlations with the other joint attention items (rs $< .30$). Principal factor analysis was used on the remaining items. The initial eigenvalues showed that the first, second, and third factors explained 31.9%, 23.8%, and 13.6% of the variance, respectively. Subsequent factors had eigenvalues of less than 1. The two- and three-factor solutions were examined using a varimax rotation of the factor-loading matrix. The two-factor solution was preferred because the third factor contained only a single item. This item was eliminated because it did not contribute to a simple factor structure and failed to meet a minimum criterion of a factor loading of .30. A principal factor analysis of the remaining seven items was conducted, with the two factors explaining 62.4% of the variance. The factor loadings for the final solution are presented in Table 1.

As can be seen in Table 1, what differentiates these factors is whether the behaviors they assess are active or responsive. The items that loaded onto Factor 1 all address active behaviors produced by infants to direct the attention of others (e.g., pointing to ask for or indicate interest in something). Items loading onto Factor 2 all assess receptive behaviors produced by infants to follow the attention of others or use it as a source of information (e.g., following gaze or points). These factors correspond to distinct dimensions of joint attention that have been identified by others in the field (e.g., Carpenter et al., 1998; Mundy et al., 2007). I adopt the terminology suggested by Seibert, Hogan, and Mundy (1982) and used extensively in the literature. The first factor, *initiating joint attention* (IJA), refers to the ability to use one's own direction of gaze or gestures to direct others' attention. The second factor, *responding to joint attention* (RJA), refers to the ability to effectively follow others' direction of gaze or gestures. Composite scores for the IJA and RJA factors were created by calculating the average score of the items loading on each factor. Possible scores ranged from 0 to 2 (IJA: $M = 0.81$, $SD = 0.54$ [$\alpha = .78$]; RJA: $M = 1.30$, $SD = 0.46$ [$\alpha = .66$]). Infants assigned to the successful and the failed reaching conditions did not differ on either IJA, $t(78) = 0.64$, $p = .52$, or RJA factor scores, $t(78) = 0.32$, $p = .75$.

Results

Two sets of analyses are presented. Initial analyses examine infants' performance in the eye-tracking task by investigating patterns of anticipatory looking to the successful and failed reaching actions. Focal analyses then explore relations between infants' performance on the experimental task and parent-report measures of infants' social and motor abilities.

Infants' Processing of Successful and Failed Intentional Actions

My first question was whether 8- to 11-month-olds demonstrated an understanding of the intended goal of the successful and failed reaching actions by producing anticipatory looks to the ball. I predicted that, consistent with Brandone et al. (2014), I would observe age differences in the likelihood of producing an anticipatory look to the ball during early trials of the failed but not the successful reaching condition. To test this prediction, I evaluated the effects of age,[1] condition (successful, failed), gender, test location (Location 1, Location 2), and trial (1–10) on the likelihood of producing an anticipatory look using the generalized estimating equations (GEE) procedure. The GEE procedure is suitable here because it can account for the binary structure of the data (producing an anticipatory look or not on a given trial) and assess both within- and between-subjects effects (Liang & Zeger, 1986). These analyses yield Wald's chi-square values as indicators of main effects and interactions. The model tested here used a binomial outcome distribution with a logit link function and a robust estimator covariance matrix.

None of the analyses revealed main effects or interactions with gender or test location; thus, these factors are not discussed further.[2] Preliminary analyses showed significant effects of trial (1–10), $\chi^2(9, N = 796) = 19.28$, $p = .023$, that were best captured by applying the strategy used in Brandone et al. (2014) and separating out the first trial and then aggregating data over triads of trials (Triad 1: Trials 2–4; Triad 2: Trials 5–7; Triad 3: Trials 8–10). The first trial is distinct from the following trials as it assessed how infants initially viewed the reaching events before they witnessed a successful or failed outcome. The remaining trials examined how infants who had seen the entire action sequence (and its success or failure) in Trial 1 adjusted their looking patterns over subsequent trials. Here, I focus on patterns of anticipatory looking during Triads 1, 2, and 3 (i.e., after infants observed an initial successful or failed reach).[3] Thus, in subsequent GEE analyses, triad was entered as a within-subject repeated-measures factor.

GEE analyses revealed a main effect of triad, $\chi^2(2, N = 716) = 6.47$, $p = .039$, and significant Triad × Age, $\chi^2(3, N = 716) = 8.47$, $p = .037$, Triad × Condition, $\chi^2(3, N = 716) = 8.02$, $p = .046$, and Triad × Condition × Age, $\chi^2(3, N = 716) = 8.93$, $p = .030$, interactions. To disentangle these interactions, I examined the effects of triad and age separately for each condition. In the successful reaching condition, analyses revealed a main effect of triad, $\chi^2(2, N = 360) = 9.37$, $p = .009$, such that infants showed an increase in the likelihood of producing an anticipatory look to the ball across triads. That is, after seeing the actor retrieve the ball successfully and consistently, infants improved their performance and produced more and more anticipatory looks to the ball. Importantly, participant age did not have a significant effect on patterns of anticipatory looking in the successful reaching condition, $\chi^2(1, N = 360) = 1.39$, $p > .24$. Effects of age were nonsignificant across all triads (ps $> .19$).

The failed reaching condition revealed a different pattern of results. Analyses supported the predicted Triad × Age interaction in the failed reaching condition, $\chi^2(3, N = 356) = 17.21$, $p = .001$. Age was a significant predictor of performance during Triad 1, $\chi^2(1, N = 120) = 4.56$, $p = .033$, such that the likelihood of producing an anticipatory look to the ball in Triad 1 of the failed reaching condition increased with age, $Exp(\beta) = 1.83$ (95% CI [1.05, 3.18]). Age was not a significant predictor in subsequent triads (ps $> .11$). Results also indicated a main effect of triad $\chi^2(2, N = 356) = 14.00$, $p = .001$, such that, overall, infants showed fewer anticipatory looks in later trials. Thus, as in Brandone et al. (2014), infants who anticipated the outcome of the failed event in initial trials sensibly modified their predictions in response to accumulating evidence of the actor's failure to achieve his goal.

These results replicate the central findings from Brandone et al. (2014).[4] First, patterns of anticipatory looking in infancy differed for successful versus failed reaching actions. Second, changes occurred between 8 and 11 months of age in the ability to generate predictions about actions that failed to achieve their goals. These findings set the stage for subsequent, focal analyses examining the factors that explain these developmental changes.

Associations Between Infants' Understanding of Intentional Actions and Their Social and Motor Development

The next analyses tested how variability in infants' understanding of intentional actions may be related to variability in infants' social and motor abilities. Motor and social behaviors included self-locomotion, means–end action abilities, and the IJA and RJA factor scores.

Associations among parent-report measures. First, associations among the different parent-report measures were examined. As can be seen in Table 2, self-locomotion, IJA, and RJA were each positively correlated with age. Self-locomotive abilities were also positively related to IJA scores. Finally, there was a significant, positive association between RJA scores and means–end abilities. No other significant associations emerged. Partial correlations were also conducted to examine associations between these behavioral measures when controlling for age. Findings indicated that the relations between self-locomotion and IJA, $r(77) = .27$, $p = .018$, and between means–end abilities and RJA, $r(77) = .25$, $p = .026$, each remained significant when controlling for age.

Associations between intentional action understanding and parent-report measures. Next, I examined associations between infants' joint attention and motor behaviors and their performance on the eye-tracking task. Bivariate correlations were conducted using the proportion of anticipatory looks in Triad 1 as the outcome variable. These correlational analyses focused on Triad 1 because, as indicated earlier, this is where effects of age and condition were observed. Separate analyses were run for the successful and failed reaching conditions because these conditions

[1] Because infants in the current study were recruited to span the range of ages between 8 and 11 months, age was treated as a continuous variable.

[2] As suggested by the absence of effects of test location, the additional participants in this study replicated key patterns reported previously in Brandone et al. (2014; i.e., effects of condition and interactions between age and triad in the failed reaching condition). This was the case both when age was treated as a continuous variable and when age was viewed categorically.

[3] As in Brandone et al. (2014), infants produced anticipatory looks infrequently in Trial 1 (on 21.3% of trials), and the likelihood of doing so did not differ by age or condition (ps $> .12$). Across all analyses presented in this article, whether the first trial was included in Triad 1 did not change the pattern of results.

[4] A repeated-measures analysis of variance using the proportion of anticipatory looks per triad as the dependent variable produced the same pattern of results: a main effect of triad, $F(2, 138) = 3.68$, $p = .028$, and Triad × Age, $F(2, 138) = 3.72$, $p = .027$, Triad × Condition, $F(2, 138) = 2.92$, $p = .057$, and Triad × Condition × Age, $F(2, 138) = 3.95$, $p = .022$, interactions. As in the GEE analyses, age was a significant predictor of performance during Triad 1 of the failed reaching condition only, $F(1, 34) = 4.98$, $p = .032$, revealing that the likelihood of producing an anticipatory look to the ball in Triad 1 of the failed reaching condition increased with age (all other ps $> .16$).

Table 2
Correlations [and Bootstrapped 95% Confidence Intervals] Between Parent-Report Measures and Age

Variable	1	2	3	4	5
1. Self-locomotion	—	.097 [−.11, .31]	.448 [.30, .58]**	.120 [−.11, .33]	.547 [.39, .67]**
2. Means–end ability		—	.145 [−.05, .34]	.283 [.04, .49]*	.196 [−.03, .40]
3. Initiating joint attention		.145 [−.05, .34]	—	.117 [−.11, .33]	.459 [.29, .60]**
4. Responding to joint attention				—	.228 [.02, .42]*
5. Age					—

* $p < .05$. ** $p < .01$.

yielded different patterns of eye-tracking results and were hypothesized to show different associations with the infant behavior measures. I predicted that associations with social and motor behaviors would be stronger for participants in the failed reaching condition because interpreting a failed action provides a clearer test of an understanding of intention.

Results confirmed these predictions (see Table 3). No association emerged between infants' social and motor abilities and the likelihood of producing an anticipatory look in Triad 1 of the successful reaching condition. A different pattern appeared for the failed reaching condition: Self-locomotive abilities and IJA scores were each positively associated with anticipatory looks to the ball in Triad 1. No associations emerged for means–end ability or the RJA factor.

Regression and mediation analyses. Next, I used hierarchical regression to determine the unique contribution of infants' self-locomotion and IJA abilities to their performance on the eye-tracking task. Given that significant associations between parent-report measures and anticipatory looking appeared in the failed reaching condition only, I focused the analyses on the failed condition. Hierarchical regression models were built to determine the relative contribution of self-locomotion (Step 1) and IJA (Step 2) to infants' performance in Triad 1 of the failed reaching condition.

As shown in Table 4, Step 1 results revealed that self-locomotion explained a significant proportion of the variance in anticipatory looking scores in Triad 1 of the failed reaching condition. In Step 2, IJA added significantly to the variance accounted for and significantly predicted the proportion of anticipatory looks. Finally, when IJA was entered in Step 2, self-locomotion was no longer a significant predictor (see Table 4).

Note that age was not included as a predictor in the focal regression model because self-locomotion and IJA abilities were hypothesized to explain the effects of age observed in this study. That is, the key causal forces behind changes in intention understanding were predicted to be infants' motor and social abilities, and age was predicted to explain differences in anticipatory looking measures only insofar as it accounted for differences in children's self-locomotion and IJA abilities. Nevertheless, to rule out the possibility that differences in failed action anticipation are a result of maturation alone, a hierarchical regression model including age as a control variable was also tested. If age alone explained differences in anticipatory looking scores, the inclusion of age in this analysis should have wiped out or severely diminished the other effects. This was not the case (see Table 5). When controlling for age, self-locomotion no longer independently predicted anticipatory looking scores in Triad 1, suggesting that the effects of self-locomotion may be driven in part by maturation; however, self-locomotion abilities remained a somewhat stronger predictor of anticipatory looking scores than age. Importantly, consistent with the previous regression analyses (see Table 4), in the final step of the model, IJA added to the variance accounted for and predicted the proportion of anticipatory looks even when controlling for age. Overall, these findings cast doubt on the possibility that maturation alone explains changes in failed action anticipation.

Finally, given the observed association between self-locomotion abilities and IJA scores, $r(77) = .45$, $p < .001$, and the results of the reported regression analyses, I also tested an exploratory mediation model in which IJA abilities mediate the association between self-locomotion and anticipatory looking during Triad 1 of the failed reaching event. I used bias-corrected bootstrapping (Preacher & Hayes, 2004, 2008) because it is considered to be the most accurate method for detecting indirect effects when sample sizes are small. The confidence interval (CI) was set to 95% with 5,000 resamples. Results indicated that although the total effect of self-locomotion on anticipatory looking was significant, $t(38) = 2.40$, $p = .021$, the direct effect was not, $t(37) = 1.33$, $p = .19$.

Table 3
Correlations [and Bootstrapped 95% Confidence Intervals] Between Infant Behavior Measures and Proportions of Anticipatory Looks to the Ball Area of Interest in Triad 1 of the Successful and Failed Reaching Conditions

Measure	Successful condition	Failed condition
Self-locomotion	.231 [−.08, .55]	.363 [.07, .64]*
Means–end ability	.046 [−.24, .37]	.088 [−.17, .35]
Initiating joint attention	.111 [−.20, .40]	.449 [.15, .70]**
Responding to joint attention	.079 [−.27, .43]	.078 [−.22, .36]

* $p < .05$. ** $p < .01$.

Table 4
Results of Hierarchical Regression Analysis Predicting Proportions of Anticipatory Looks in Triad 1 of the Failed Reaching Condition from Self-Locomotion and Initiating Joint Attention

Independent variable	R^2	ΔR^2	ΔF	F	β	t
Step 1	.13			5.77*		
Self-locomotion					.36	2.40*
Step 2	.24	.11	5.22	5.79**		
Self-locomotion					.21	1.33
Initiating joint attention					.36	2.27*

Note. $n = 40$.
* $p < .05$. ** $p < .01$.

Table 5
Results of Hierarchical Regression Analysis Predicting Proportions of Anticipatory Looks in Triad 1 of the Failed Reaching Condition from Age, Self-Locomotion, and Initiating Joint Attention

Independent variable	R^2	ΔR^2	ΔF	F	β	t
Step 1	.11			4.76*		
Age					.33	2.18*
Step 2	.17	.056	2.47	3.70*		
Age					.21	1.24
Self-locomotion					.27	1.57
Step 3	.25	.084	4.01	4.01**		
Age					.13	0.76
Self-locomotion					.17	0.97
Initiating joint attention					.33	2.00†

Note. $n = 40$.
† $p = .053$. * $p < .05$. ** $p < .01$.

Bootstrapping analyses also showed that infants' IJA abilities significantly mediated the association between self-locomotion and anticipatory looks during Triad 1 of the failed reaching event (95% CI [.0024, .0730]). These findings lend support to the mediational model predicting that changes in joint attention abilities resulting from the onset of self-locomotion explain the association between self-locomotion abilities and infants' understanding of others' intentional actions.

Discussion

The goal of this article was to shed light on the developmental mechanisms underlying changes in infants' understanding of intentional actions by documenting relations between infants' intention understanding and other emerging social and motor abilities in the first year of life. Findings confirmed prior data showing improvements in infants' ability to interpret and make predictions about others' failed intentional actions between 8 and 11 months of age (Brandone et al., 2014; Brandone & Wellman, 2009). In addition, I found that parent-report measures of infants' IJA and self-locomotion abilities were associated with infants' ability to predict the outcome of a failed (but not a successful) reaching action. Specifically, the current study provides the first evidence that variability in the extent to which infants use gestures and gaze to guide the attention of others (the IJA factor) predicts their ability to anticipate the goal of a failed action. This study is also the first to show an association between self-locomotion ability and infants' ability to make predictions about the goal of a failed intentional action. Finally, exploratory mediation analyses showed that infants' joint attention abilities substantially mediate the association between self-locomotion and the ability to predict the outcome of the failed action, raising the intriguing possibility that self-locomotion may shape the development of intention understanding by altering infants' experience with those around them and inviting opportunities for joint-attentive interactions. Overall, these data are consistent with the view that learning opportunities available in infants' social and motor experience may contribute to changes in their social–cognitive abilities.

Notably, associations between infants' social and motor behaviors and their action-processing abilities emerged in the current study in the failed reaching condition only. There were no significant correlations between any behaviors assessed on the parent questionnaire and infants' anticipatory looks to the ball in the successful condition. Recall that reasoning about the goal of a failed action has been argued to provide a different, more diagnostic test of intention understanding than does reasoning about the goal of a successful action. This is because, unlike in an action that successfully accomplishes its goals, the outcome and observed pattern of motion in a failed action are distinct from the internal state motivating them (see Meltzoff, 1995). Thus, the fact that significant associations only emerged in the failed reaching condition suggests that joint attention and self-locomotion experience are uniquely related to (and possibly play a role in the development of) the robust, complex intentional understanding of human behavior that emerges late in the first year.

It is important to note that the design used in the current study only allows me to evaluate concurrent relations between infants' motor and social behaviors and their intention understanding. There is no way to be certain about the direction of causation that may account for the associations observed. Moreover, conclusions must also be limited because of the fact that estimates of infants' motor and social behaviors were derived from parent-report questionnaires. Longitudinal studies that involve direct observations of motor and social behaviors are needed to more precisely examine how the relations between understanding intention, IJA, and moving independently play out over the course of development. Nevertheless, an important question arising from the current data concerns what explains the observed associations.

Consider first the association between infants' failed action understanding and their ability to initiate joint attention. Some researchers have argued that an understanding of intention is required for the later development of joint attention in infancy (Tomasello, Carpenter, Call, Behne, & Moll, 2005). On this view, an understanding of others as intentional agents provides the foundation and motivation for joint-attentive interactions, and joint attention is thus a behavioral manifestation of infants' underlying intention understanding. Others have argued that joint attention experience is a predictor rather than an outcome of the development of intention understanding (Corkum & Moore, 1995; Mundy & Newell, 2007). On this view, joint attentive interactions provide the rich experiences necessary for infants to acquire a view of others as intentional agents. The current data cannot speak directly to the question of causation. Moreover, given the parent-report nature of the joint attention measures, it remains possible that parents' perception of infants' initiation of joint attention rather than infants' joint attention ability itself may be driving the association. That is, parents who are more attentive to infants' interactions and joint attention behaviors and thus more likely to report that their infants are initiating joint attention may have infants who are better able to understand others' intentions. Nevertheless, the current data provide initial empirical support for the proposal that IJA behaviors and intention understanding are tightly related.

These findings are also consistent with research documenting relations between specific joint attention behaviors and an understanding of those behaviors in others. For example, Brune and Woodward (2007) and Woodward and Guajardo (2002) found that between 9 and 12 months of age, infants who produced object-directed points were more likely than those who did not yet produce such points to interpret the pointing behavior of others as relational in a visual habituation task. Brune and Woodward also found that shared attention (measured by the proportion of time infants and their primary caregivers spent in a state of joint engagement with an object during a free-play period) was systematically related to infants' understanding of the goal directedness of a gaze event (in a habituation task). However, relations across these sets of measures were not significant; that is, pointing behavior was not related to understanding the goal directedness of gaze, and shared attention was not related to understanding pointing. On the basis of these findings, Brune and Woodward (2007) concluded that infants use their social experience to develop relatively isolated "pockets of knowledge" (p. 155) about particular actions that only later become integrated in a coherent concept of intention. The current findings, however, suggest that by the end of the first year, infants may also possess a broader notion of people as intentional agents that is importantly related to their tendency to initiate rich joint-attentive social interactions. More research is needed to evaluate whether and when infants integrate their piecemeal knowledge about others' actions into a unified concept of intention and the role that experience in joint-attentive social interactions may play in the process.

Consider next the observed association between self-locomotion ability and infants' tendency to produce anticipatory looks during the failed reaching event. Standard approaches to exploring the relation between motor experience and action understanding examine how experience producing a specific type of goal-directed action is related to the ability to interpret that action alone (for reviews, see Gerson & Woodward, 2010; Woodward et al., 2009; but see Skerry et al., 2013, for a different approach). The current results move beyond this argument and suggest that experience as an intentional agent more broadly may also influence infants' views of others' intentionality.

One interpretation of this relation is that the ability to locomote independently is important for intention understanding because it provides a powerful opportunity for infants to act on their own intentions and, thus, offers broad insight into both infants' own and others' intentionality. This view is plausible given research showing that crawling is a key developmental milestone that transforms infants' experience and interactions with their environment (Campos et al., 2000). A distinct (but not mutually exclusive) possibility is that the power of self-locomotion experience is indirect—in the ways in which it transforms infants' social interactions. Locomotion represents more than just a motor milestone: learning to crawl and walk are also associated with changes in infants' social behaviors, including greater attention to distal social events and increased time in interactive play games and distal communicative interactions with caregivers (Campos et al., 2000; Clearfield, 2011; Karasik, Tamis-LeMonda, & Adolph, 2011). The mediational analyses presented in the current study are consistent with the hypothesis that self-locomotion may contribute to an emerging understanding of intention by way of the effects it has on joint attention. However, given limitations of the current paradigm for drawing causal conclusions, further research is needed to systematically test this hypothesis. Additional research is also required to disentangle the effects of self-locomotion and those of maturation alone.

Another important question arising from the current data concerns the absence of relations between infants' failed action understanding and their RJA and means–end action abilities. In both cases, these null results could reflect methodological issues. For example, failure to find evidence of an association between intention understanding and means–end abilities may well be attributable to the imprecision of the measure used to assess means–end action production: a single parent-report item. Likewise, the absence of an association between RJA scores and infants' failed action understanding may be attributable to measurement issues. Scores on the items loading on the RJA factor were consistently high and showed low variability, decreasing the likelihood of finding an association if one exists. These items were also less active in nature and may have been more challenging for parents to assess. If that was the case, data from these items would have been less accurate and the factor less sensitive (but see Brune & Woodward, 2007, for similar findings using observational measures of infants' gaze and point following).

A more interesting explanation is that the RJA factor shows a distinct pattern of associations from the IJA factor because each reflects a unique dimension of joint attention that is differentially related to intention understanding. This possibility is supported by research showing that these factors display different patterns of age-related growth in infancy, have unique associations with later development, and reflect different underlying processes (Mundy et al., 2007). For example, RJA is associated with parietal activity in the brain and may be part of a relatively reflexive system of orienting to biologically meaningful stimuli that develops early in the first year of life (for a review, see Mundy, Card, & Fox, 2000; see also Barresi & Moore, 1996; Corkum & Moore, 1995). In contrast, IJA is associated with activation of frontal brain areas (Mundy et al., 2000) and may be part of a more volitional attention system that develops later in infancy (e.g., Rothbart, Posner, & Rosicky, 1994). On this view, the more purposeful use of behaviors such as eye contact or gestures to initiate coordinated attention with a social partner may be more clearly linked with infants' understanding of intention. Further research across a larger developmental window is necessary to more precisely document how infants' IJA and RJA behaviors may be related to the development of intention understanding.

In conclusion, existing research examining infants' understanding of the intentional structure of others' actions supports both early competencies (for a review, see Woodward et al., 2009) and important developmental change (e.g., Brandone et al., 2014; Brandone & Wellman, 2009). Although the understanding present in young infants is consistent with the possibility that infants possess an innate computational system for reasoning about intentional actions (e.g., Bíró & Leslie, 2007; Gergely & Csibra, 2003), a different theoretical account must be offered to explain how infants' understanding of intentional action changes in the second half of the first year of life. The current study demonstrates that changes in infants' social and motor experience during this time are also related to their developing understanding of intentional actions. Future research is needed to examine the promising possibility that joint-attentive social interactions that occur with increasing frequency as infants learn to crawl and walk may shape their understanding of others as intentional agents. The questions of how these mechanisms work together and how they enrich or build on infants' earlier understandings remain important directions for future research.

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