PAPER

Developmental Science 🦊 WILEY

Triadic interactions support infants' emerging understanding of intentional actions

Amanda C. Brandone[1] | Wyntre Stout[1] | Kelsey Moty[2]

[1]Department of Psychology, Lehigh University, Bethlehem, Pennsylvania

[2]Department of Psychology, New York University, New York, New York

Correspondence
Amanda C. Brandone, Department of Psychology, Lehigh University, Bethlehem, PA 18015.
Email: acb210@lehigh.edu

Abstract

Infants' understanding of the intentional nature of human action develops gradually across the first year of life. A key question is what mechanisms drive changes in this foundational social-cognitive ability. The current studies explored the hypothesis that triadic interactions in which infants coordinate attention between a social partner and an object of mutual interest promote infants' developing understanding of others as intentional agents. Infants' spontaneous tendency to participate in triadic engagement was assessed in a semi-structured play session with a researcher. Intentional action understanding was assessed by evaluating infants' ability to visually predict the goal of an intentional reaching action. Study 1 (N = 88) revealed that 8- to 9-month-olds who displayed more bouts of triadic engagement showed better concurrent reasoning about the goal of an intentional reaching action. Study 2 (N = 114) confirmed these findings using a longitudinal design and demonstrated that infants who displayed more bouts of triadic engagement at 6–7 months were better at prospectively reasoning about the goal of an intentional reaching action 3 months later. Cross-lagged path analyses revealed that intentional action understanding at 6–7 months did not predict later triadic engagement, suggesting that early triadic engagement supports later intentional action processing and not the other way around. Finally, evidence from both studies revealed the unique contribution of triadic over dyadic forms of engagement. These results highlight the importance of social interaction as a developmental mechanism and suggest that infants enrich their understanding of intentionality through triadic interactions with social partners.

KEYWORDS
cognitive development, infancy, intention understanding, joint engagement, social cognition, triadic interaction

1 | INTRODUCTION

Infants' understanding of the intentional nature of human actions develops gradually across the first year of life (Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009). Research using looking-time and eye-tracking methodologies has documented the systematic unfolding of this knowledge across infancy. Babies as young as 5–6 months of age represent basic reaching actions as intentional (Woodward, 1998); at 6–8 months, infants visually anticipate the endpoint of goal-directed reaches before the hand makes contact (Kanakogi & Itakura, 2011); and by 11 months, infants make predictions about the goals and not simply the physical endpoints of reaching actions (Cannon & Woodward, 2012). The ability to interpret more complex intentional actions—including pointing (Woodward & Guajardo, 2002), multi-step sequences (Sommerville & Woodward, 2005), collaborative actions (Henderson

& Woodward, 2011), and actions that fail to achieve their goals (Brandone & Wellman, 2009)—emerges relatively later in infancy. For example, although infants can interpret an actor reaching over a barrier and successfully retrieving a ball by 8 months, the ability to reason about a parallel failed action does not appear until a few months later (Brandone, Horwitz, Wellman, & Aslin, 2014; Brandone & Wellman, 2009). Although much is known about when these milestones toward a concept of intentionality are achieved, less is known about how infants accomplish them.

Currently, most prominent accounts of developmental changes in action understanding focus on infants' own experience as intentional agents. Many have argued that infants' first-person experience of intentional agency influences their understanding of others' actions (Daum, Prinz, & Aschersleben, 2011; Gallese, Rochat, Cossu, & Sinigaglia, 2009; Gredebäck & Falck-Ytter, 2015; Woodward et al., 2009). Support for this proposal comes from research documenting systematic relations between actions infants can produce themselves and those they can interpret in others. For example, at 6 months—when infants begin to make skilled intentional grasps—infants begin to understand the intentional reaches of others (Kanakogi & Itakura, 2011; Woodward, 1998). Likewise, it is not until infants can competently place objects inside containers that they make anticipatory gaze shifts while watching this action performed by others (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Falck-Ytter, Gredebäck, & von Hofsten, 2006). Further support comes from experimental manipulations that alter infants' action capacities and observe the effects on infants' action perception. For example, after 3-month-olds (who are not yet skilled in goal-directed grasping and do not understand others' grasps as goal-directed) received experience manipulating the movement of toys using Velcro mittens, they interpreted an experimenter's reaches as goal-directed (Gerson & Woodward, 2013; Sommerville, Woodward, & Needham, 2005). These results imply that infants' first-person experiences provide powerful insight into others' actions.

The capacity to generate intentional actions is likely only one part of a larger set of experiences that impacts infants' emerging social cognition. Another likely source of information is infants' interactions with social partners—in particular, triadic interactions in which infants coordinate attention between a social partner and an object of mutual interest (also referred to as joint attention or joint engagement; Trevarthen & Hubley, 1978). Several theories of social-cognitive development propose that experience in triadic interaction facilitates infants' emerging understanding of intentionality (Barresi & Moore, 1996; Carpendale & Lewis, 2004; Hobson, 2002). For example, according to Barresi and Moore (1996), triadic interactions are critical to developing a representation of one's own and others' actions as intentional. They argue that information about intentional relations between agents and objects is available from two distinct sources: first-person experience with one's own intentional activity and third-person information gleaned from observing others' intentional actions. When infants participate in triadic interactions in which their own actions are aligned with and directed at the same object as their social partner's, it creates the conditions necessary

Research Highlights

- Triadic interactions in which infants coordinate attention between a social partner and an object of mutual interest are proposed to influence infants' developing intention understanding.
- Cross-sectional evidence revealed that infants who displayed more triadic engagement during play showed better concurrent reasoning about the goal of an intentional reaching action.
- Longitudinal evidence further demonstrated that levels of triadic engagement at 6–7 months of age predicted infants' intentional action processing 3 months later.
- These results suggest that accumulating experience in triadic interaction across infancy may promote the development of intentional action understanding.

for infants to bridge the gap between first- and third-person information. Only when these conditions are met can a conceptual system that equally represents one's own and others' intentional actions be generated. On this and related views (Carpendale & Lewis, 2004; Hobson, 2002), triadic interactions create the unique social environment in which the development of intention understanding can unfold and thus play a pivotal role in the emergence of this knowledge.

Despite the prominence of these theoretical claims, little research has tested the role of triadic interaction as a mechanism in the development of an understanding of intentionality. Some initial support can be seen in the temporal alignment of the acquisition of triadic interaction and intentional action understanding. Studies suggest that triadic interactions arise gradually near the end of the first year (Carpenter, Nagell, & Tomasello, 1998; Tomasello, 1999; Trevarthen & Hubley, 1978). For example, Bakeman and Adamson (1984) documented a decrease in dyadic face-to-face play and an increase in triadic interactions between 6 and 15 months. Longitudinal studies assessing infants' joint-attention skills (e.g., joint engagement, gaze following, pointing) have shown a similar pattern. Between 5 and 10 months, most infants pass at least some joint-attention tasks (Striano & Bertin, 2005; Striano, Stahl, & Cleveland, 2009); however, infants show increasing proficiency near the end of the first year (Carpenter et al., 1998). These shifts toward greater time in and success at triadic engagement parallel the increase in intentional action understanding observed in experimental tasks during the first year (e.g., Brandone et al., 2014; Cannon & Woodward, 2012). Although falling short of demonstrating a causal pathway, this alignment suggests that it is at least plausible that experiences within triadic engagement contribute to infants' understanding of intentional actions.

Three studies have directly investigated relations between individual variability in triadic engagement and intentional action knowledge. Brune and Woodward (2007) examined how long 9- to 11-month-olds and their caregivers spent in joint engagement and infants' performance on a task assessing the actor-object relation

in a gaze event. Dunphy-Lelii, LaBounty, Lane, and Wellman (2014) investigated 10–12-month-olds' joint-attention behaviors with a caregiver and their habituation to a person emoting at one of two objects (see also Brink, Lane, & Wellman, 2015). Finally, Brandone (2015) analyzed parental reports of 8–11-month-olds' joint-attention tendencies and their visual anticipation of the outcome of a failed reach. Despite key differences in methodologies, each of these studies showed systematic relations between measures of triadic engagement and intentional action processing: infants who spent greater time in triadic engagement or displayed more joint-attention abilities performed better on assessments of intentional action understanding.

Although these studies provide evidence consistent with the notion that triadic engagement serves as a mechanism in the development of intention understanding, their concurrent, correlational nature limits the conclusions that can be drawn. Findings may imply that joint engagement leads to the discovery of others' intentions and plays a causal role in the development of intentional action processing (Barresi & Moore, 1996). Conversely, results may indicate the reverse causal relation—that intentional action understanding enables infants to participate in triadic engagement (Tomasello, 1999). Finally, these associations may suggest that both joint engagement and intentional action processing are behavioral manifestations of another cognitive or social achievement. Longitudinal work is needed to disentangle these possibilities and test the directionality of these relations.

1.1 | The current studies

We present two studies investigating whether triadic engagement serves as a mechanism in the development of intentional action understanding. Both studies assessed relations between infants' tendency to engage in triadic interactions and their ability to make predictions about intentional reaching actions. Following models in prior work (Brandone, 2015; Brune & Woodward, 2007; Dunphy-Lelii et al., 2014), Study 1 established these relations in a concurrent design with infants at 8–9 months—a time when the shift toward greater triadic engagement is beginning (Bakeman & Adamson, 1984) and changes in intentional action understanding are unfolding (Brandone et al., 2014). Study 2 used a longitudinal design to examine whether the tendency to engage in triadic interaction at 6–7 months predicted intention understanding roughly 3 months later.

In both studies, we assessed triadic engagement using a semistructured play session. We examined interactions with an experimenter rather than a familiar caregiver to eliminate variability in caregiver interactive style as a factor in infants' triadic engagement (Gaffan, Martins, Healy, & Murray, 2010). As in Carpenter et al. (1998), we coded bouts of triadic engagement defined as gaze alternations between an object, the experimenter's face, and the same object. Furthermore, we differentiated dyadic and triadic engagement by coding the frequency of looks to the experimenter's face outside of triadic engagement. If triadic engagement is critical for constructing a concept of intentionality, social attention within

triadic rather than dyadic contexts should predict infants' understanding of intention.

To assess intentional action understanding, we examined infants' ability to generate predictions about ongoing intentional actions using an eye-tracking procedure. Eye tracking enables researchers to evaluate prospective judgments about an action by measuring anticipatory-looking patterns (i.e., whether infants look to the goal of the action before it is completed). This prospective understanding of behavior is crucial for interpreting actions as they unfold over time and serves as a strong test of intentional action understanding (Krogh-Jespersen, Liberman, & Woodward, 2015).

In both studies, we tested infants' anticipatory responses to a failed reaching action. We examined failed actions for three reasons. First, actions in which the observed patterns of motion (e.g., reaching for but failing to grasp a ball) are distinct from their intentions (e.g., grasping and retrieving a ball) have been argued to provide a more robust test of intention understanding than actions that successfully achieve their goals (Meltzoff, 1995). Second, infants' understanding of failed actions undergoes important changes late in the first year (Brandone et al., 2014; Brandone & Wellman, 2009). Third, prior work has established links between infants' failed action processing and their tendency to initiate joint attention as assessed by parent report (Brandone, 2015).

Study 2 also included a measure of successful action understanding at both time points. The ability to make predictions about successful reaching actions has been shown to emerge earlier than failed action understanding (Brandone et al., 2014; Brandone & Wellman, 2009). Thus, the successful action task was included as a measure of more basic understanding and to be a more appropriate assessment for the 6- to 7-month-olds in Study 2.

We hypothesized that experience in triadic interactions helps drive advances in understanding intentional actions (Barresi & Moore, 1996). Thus, we predicted that infants who show more triadic engagement will demonstrate more advanced concurrent intentional action understanding. In addition, we predicted that infants who experience more opportunities for triadic engagement as 6- to 7-month-olds will show better intentional action understanding later in infancy.

2 | STUDY 1

2.1 | Method

2.1.1 | Participants

One hundred 8- to 9-month-olds participated. Twelve infants were excluded for recording problems during eye tracking (4) or the triadic engagement task (2), insufficient eye-tracking data (5), and fussiness that prevented study completion (1). The final sample included 88 infants (M = 8.72 months, SD = 0.44; Range: 7.63–9.73; 42 males, 46 females; 67% White, 33% other races/ethnicities). Infants came from families that were predominantly middle class (75% had household incomes of $59,000 or greater) and college-educated (82%
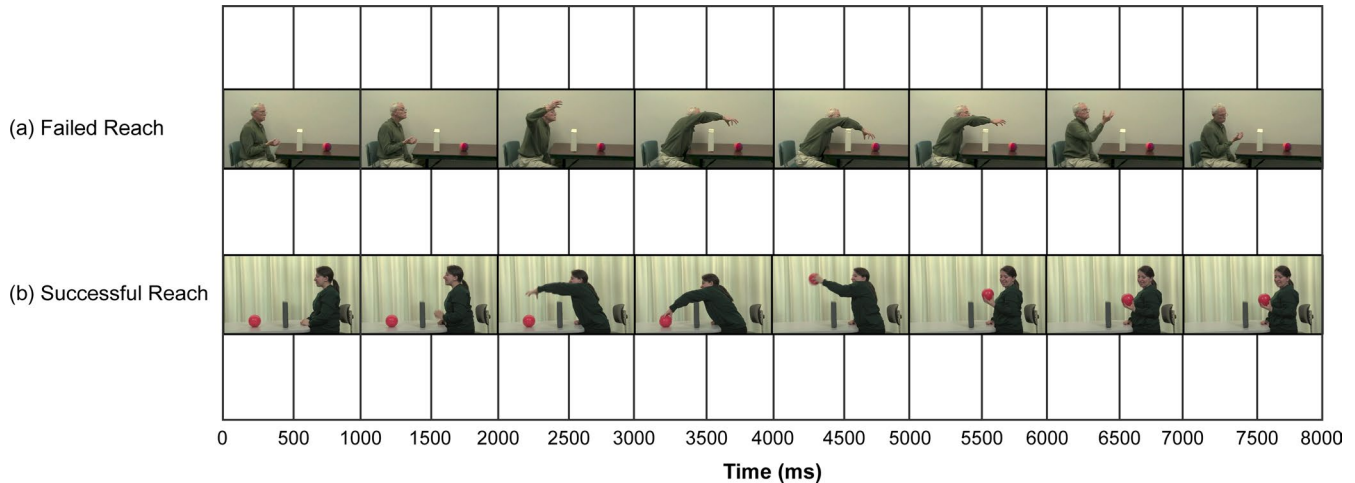
FIGURE 1 Time course depiction of the (a) failed (Study 1 & 2) and (b) successful (Study 2) reaching events

of mothers had college or advanced degrees). Participants were recruited from birth records in a midsize city in the Northeastern United States. Families were compensated $20 for participation. Both studies were approved by the Institutional Review Board at Lehigh University. Informed consent was obtained from all parents prior to data collection.

2.1.2 | Measures and procedures

During a single laboratory visit, infants completed an eye-tracking measure of failed action understanding, a triadic engagement measure, and several tasks that are beyond the scope of this paper (e.g., free play, assessments of motor abilities). See https://osf.io/y8upz/ for supporting materials and data for both studies. All infants completed the intentional action understanding task first; the triadic engagement measure occurred later in the session.

Intentional action understanding

Infants were shown a video of a failed reaching event similar to that used in prior work (Brandone et al., 2014; see Figure 1a). In the video, an actor was seated at a table in front of a barrier and a ball. The event began with the actor gazing over the barrier at the ball. He then reached in an arcing motion over the barrier, narrowly missing the ball. After hovering with his hand suspended above the ball, the actor brought his hand back to his torso. The video froze with the man looking at his empty hand with a disappointed expression. The event was 7,200 ms in duration, followed by an 800 ms still frame. Participants watched 10 repetitions. On the first trial only, the initial frame was presented for 2,000 ms before the video began to orient infants to the scene. Trials were alternated with an attention-getting stimulus. Half of infants watched a video where the actor was seated on the left side of the screen and reached for a ball on the right; the other half watched the inverse video.

Stimuli were presented on a 24-inch Tobii T60XL corneal reflection eye-tracking system (sampling rate: 60 Hz; accuracy: 0.5–1°;

Tobii Technology, Sweden). Infants sat in a highchair or on a parent's lap 60 cm from the screen. The eye tracker was calibrated for each participant using a 5-point procedure implemented through Tobii Studio (Tobii Technology, Sweden). Video presentation was controlled by PsyScope X (http://psy.ck.sissa.it/) and the TobiiPlus interface (Papp & Fillippin, 2014).

Eye-tracking data processing was carried out in R (Version 3.3.2; R Core Team, 2017). We defined a circular area of interest (AOI) extending approximately 1° beyond the ball. This buffer was selected based on previous work (Brandone et al., 2014), standards in the field (Gredebäck, Johnson, & von Hofsten, 2009), and estimates of inaccuracies in the system. Trials on which a participant watched the screen for less than 50% of the reaching action (14% of trials) were dropped. Participants who contributed usable data on fewer than 50% of trials were excluded from analyses as this pattern suggests inattentiveness or poor eye-tracking data quality ($n = 4$).

Analyses examined the mean latency of gaze shifts to the AOI and the proportion of gaze shifts that were considered anticipatory. These provide complementary but unique measures of action processing. The latency measure provides a pure assessment of how long it takes for infants to look at the AOI, but excludes trials on which participants do not look at the AOI (51.4% of trials) and infants who never look at the AOI ($n = 18$). The proportion measure includes all infants, but relies on an anticipatory-looking criterion that treats looking behavior categorically. Anticipatory looks are typically defined as gaze shifts to an action's goal before the action is completed (e.g., Falck-Ytter et al., 2006). Because the failed action is never technically completed, following prior work (Brandone et al., 2014), we defined anticipatory looks using a criterion that involves a distance between the actor's hand and the ball. Roughly 2° was selected because this was the distance between the hand and ball at the full extension of the failed reach. Anticipatory looks were thus defined as fixations to the AOI occurring before the actor's hand was 2° from the ball.

Initial analyses revealed no effect of trial on infants' likelihood of producing an anticipatory look or latency of looking to the AOI.

Because patterns of anticipatory looking did not change across trials but the likelihood of producing unusable data (i.e., dropped trials or trials with no look to the AOI) increased significantly in the second half of trials, $\chi^2(1, N = 920) = 6.85$, $p = 0.009$, we focused subsequent analyses on the first half of trials (Trials 1–5). One participant with fewer than two usable trials in the first half was excluded from analyses, leaving a final sample of 88 infants in the proportion analyses and 70 in the latency analyses.

Triadic engagement

Triadic engagement was assessed through a 2-min play session in which infants were seated in a highchair at a table across from a researcher. The task began after the researcher arranged a set of toys on the table. The researcher briefly engaged the infant with a toy once every 30 s. During the remainder of the session she sat neutrally and responded only following infants' looks to her face. The researcher responded by making eye contact, displaying a positive facial expression, and providing brief verbal comments (e.g., "What do you have?", "Wow!"). The researcher also followed infants' gaze if they shifted back to the toy, and re-established eye contact if infants looked back at her face. Throughout the session, the researcher monitored the infant's behavior and attention such that at any point she was available for and responsive to triadic engagement.

As in Carpenter et al. (1998), triadic engagement was coded when infants looked from an object to the researcher's face, and back to the same object. Bouts of triadic engagement could include one or more of these object-face-object sequences so long as infants' attention alternated between the researcher and the same object. Once infants' attention shifted to a new toy or element in the environment, the bout ended. Bouts were coded during the periods when the researcher engaged infants with a toy and when infants engaged the researcher between those periods. Thus, this triadic engagement measure included both researcher- and infant-initiated bouts.

Video recordings of the interactions were coded using Datavyu (Datavyu Team, 2014) by a team of four trained researchers (see https://osf.io/y8upz/ for the full coding scheme and coding training procedures). In the first coding pass, a member of the coding team identified the onset and offset of each look to the researcher's face. In the second coding pass, a member of the coding team used the marked face looks to identify bouts of triadic engagement. After each pass, 30% of videos ($n = 28$) were independently coded by an additional member of the coding team. For each infant, we calculated the total number of bouts of triadic engagement and the total number of face looks outside triadic engagement during the 2-min task.

To examine agreement between coders, for each variable (occurrence of face looks, bouts of triadic engagement, face looks outside triadic engagement), we identified the total number of behaviors coders agreed upon (e.g., face looks coded by both coders) and the total number of behaviors coders disagreed about (e.g., face looks coded by one but not both coders). We then calculated the percentage of behaviors agreed upon out of the total number of coded behaviors (agreements plus disagreements). Results showed high levels of agreement for the occurrence of face looks (97%), bouts of triadic engagement (85%), and face looks outside triadic engagement (88%). For each of the double-coded videos, we also calculated the total number of face looks, bouts of triadic engagement, and face looks outside triadic engagement coded by each coder. Strong correlations between coders were observed for each variable (rs = 0.99, 0.90, and 0.96 for the total number of face looks, bouts of triadic engagement, and face looks outside triadic engagement, respectively).

As a final confirmation of the accuracy of the data, all bouts of triadic engagement identified by the initial coder in 100% of videos were reviewed by an expert coder to verify that they met the coding criteria. Of these bouts, 91% were confirmed. When disagreements occurred, the expert coder's coding was retained. Although this deviates from conventional reliability procedures, it is justified here due to the expertise of the expert coder, the simplicity of the behaviors coded, and the fact that all coders, including the expert, were blind to infants' performance on the eye-tracking task.

2.2 | Results

Descriptive statistics are shown in Table 1 along with correlations with age and gender. No correlations with age or gender reached statistical significance.

Focal analyses examined whether infants who displayed more triadic engagement demonstrated superior intentional action understanding. Path models were built in MPLUS (Muthén & Muthén,

TABLE 1 Descriptive data and correlations with age and gender for Study 1

Variable	Mean	SD	Range	Correlation with age	Correlation with gender[a]
1. Failed reach: prop anticipatory looks	0.22	0.28	0 to 1	0.199[+]	0.131
2. Bouts of triadic engagement	2.77	1.65	0 to 6	0.185[+]	−0.008
3. Face looks outside of triadic engagement	6.36	3.93	0 to 17	0.043	−0.185[+]

[a]A point-biserial correlation was tested using gender as a dichotomous variable (males = 0, females = 1). This analysis yields results equivalent to an independent samples t test.
[+]$p < 0.10$.

1998–2017) regressing the proportion of anticipatory looks and mean latency of looking to the AOI onto bouts of triadic engagement. Results showed that in both models, bouts of triadic engagement contributed significantly to infants' intentional action understanding: infants who displayed more bouts of triadic engagement produced more anticipatory looks (β = 0.231, p = 0.014) and were faster to shift their gaze to the ball during the intentional reaching task (β = −0.320, p = 0.008).

Next, age was entered in the models as a covariate to examine whether bouts of triadic engagement contributed over and above the effects of age. Results showed that age was not a significant predictor of intentional action understanding (both ps > 0.12) and including this variable in the models did not change the significance of the paths from triadic engagement to intentional action understanding (both ps < 0.05).

To further differentiate the role of triadic versus dyadic forms of engagement, we built another set of models including infants' frequency of face looks produced outside triadic engagement as an additional predictor. Dyadic engagement did not emerge as a significant predictor (both ps > 0.46) and including this variable in the models did not change the significance of the paths from triadic engagement to intentional action understanding (both ps < 0.05).

2.3 | Discussion

Study 1 results provide clear support for the role of triadic engagement in the development of intentional action understanding (Barresi & Moore, 1996). These data confirm studies documenting concurrent relations between triadic engagement and performance on experimental assessments of intention understanding (Brandone, 2015; Brune & Woodward, 2007; Dunphy-Lelii et al., 2014). Moreover, our findings help fine-tune conclusions from prior work by highlighting the importance of participation in triadic engagement over and above dyadic forms of interaction. Nevertheless, the directionality of this association cannot be addressed given the concurrent nature of our data. It remains unclear whether triadic engagement drives the development of intentional action understanding (Barresi & Moore, 1996) or whether intentional action understanding enables participation in triadic engagement (Tomasello, 1999).

In Study 2, we used a cross-lagged, longitudinal design to shed light on this question. We assessed intentional action processing and participation in triadic engagement at two time points. We tested 6- to 7-month-olds at Time 1 because infants at this age are beginning to engage in triadic interactions (Bakeman & Adamson, 1984) and are capable of representing basic reaching actions as intentional (Woodward, 1998); however, their understanding of more complex intentional actions (e.g., those that fail to achieve their goals) is still emerging. Infants' Time 2 visit occurred roughly three months later. Using this design, we tested whether the tendency to participate in triadic interaction at 6–7 months predicted infants' ability to process an intentional reaching action later in the first year.

3 | STUDY 2

3.1 | Method

3.1.1 | Participants

128 6- to 7-month-olds participated at Time 1. Infants were invited to return to the laboratory after they became proficient at crawling (i.e., parents reporting infants crawling 8–10 feet across the room without stopping; Adolph, Berger, & Leo, 2011). The use of crawling proficiency to determine the timing of infants' second visit was motivated by evidence of the potential role of self-locomotion in the development of intentional action understanding; however, this issue is beyond the scope of the current paper (for further discussion, see Brandone, 2015). One hundred and fourteen participants returned to the laboratory at Time 2 (58 males, 56 females; 75% White, 25% other races/ethnicities). The average age at Time 1 was 6.86 months (Range: 6.21–7.77, SD = 0.31). Given variability in the age of crawling proficiency, infants' age at Time 2 and the time between visits varied widely. The average age at Time 2 was 9.81 months (Range: 7.67–12.53, SD = 1.04). On average, infants returned to the laboratory 2.95 months after their first visit (Range: 0.86–5.69, SD = 1.07). Infants came from families that were predominantly middle class (75% had combined incomes of $59,000 or greater) and college-educated (74% of mothers had college or advanced degrees). Participants were recruited in the same manner as in Study 1. None of the infants participated in Study 1. Families were compensated $20 per visit.

3.1.2 | Measures and procedures

During both visits, infants completed two eye-tracking measures of intentional action understanding (failed and successful reaching), a triadic engagement measure, and several tasks that are beyond the scope of this paper. During each visit, all infants completed the intentional action understanding tasks first; the triadic engagement measure occurred later in the sessions.

Intentional action understanding

The eye-tracking procedure occurred as in Study 1. Following calibration, the failed reaching event was presented. Then, after a brief distractor task, infants were presented with the successful reaching event (see Figure 1b). In this video, a woman reached over a barrier and successfully retrieved a ball. The video began with a sequence in which she gazed over the barrier at the ball. She then reached in an arcing motion over the barrier, grasped the ball, and brought it back to her torso. The video froze with the actor holding the ball and smiling. This event was 5,200 ms in duration, followed by a 2,800 ms still frame. Infants who watched the man reach left-to-right for the failed reaching event watched the woman reach right-to-left for the successful reaching event and vice versa.

Presentation of the video stimuli was identical at both time points except for the following differences. First, the left-right orientation of the videos differed to ensure that infants did not see the

same video during both visits. Second, the number of failed reaching trials differed. To minimize the duration of the eye-tracking session at Time 1, we presented only five trials of each event; at Time 2, we presented 10 trials of the failed and five trials of the successful reaching event. In all analyses of Time 2 failed reaching, we focus on the first five trials only to equate the number across visits and reaching events and because the likelihood of producing unusable data increased in the second half of failed trials, $\chi^2(1, N = 1,140) = 6.59$, $p = 0.010$.

Gaze data processing was similar to that executed in Study 1. Trials on which a participant watched the screen for less than 50% of the reaching action were excluded from the data (Time 1:14% of failed, 18% of successful trials; Time 2:9% of failed, 15% of successful trials). The AOI described in Study 1 was used for the failed reaching event. A size-matched AOI was created for the successful event. As in Study 1, we defined anticipatory looks using a criterion that involves a distance of roughly 2° between the hand and ball. The same distance was used for both failed and successful reaching actions.

Triadic engagement

Triadic engagement was assessed and coded at both time points following the procedure described in Study 1. An additional coder independently coded 30% of videos ($n = 34$). Agreement between coders was high for the occurrence of face looks (Time 1:90%, Time 2:92%), bouts of triadic engagement (Time 1:82%, Time 2:82%), and face looks outside triadic engagement (Time 1:93%, Time 2:89%). Strong correlations across coders were also observed for the total number of face looks, bouts of triadic engagement, and face looks outside triadic engagement reported for each participant (Time 1: rs = 0.97, 0.92, 0.98; Time 2: rs = 0.98, 0.92, 0.96). All bouts of triadic

engagement identified by the initial coder in 100% of videos were verified by an expert coder. Of these bouts, 91% were confirmed at Time 1 and Time 2. When disagreements occurred, the expert coder's coding was retained.

3.2 | Results

3.2.1 | Descriptive and preliminary analyses

Descriptive statistics are shown in Table 2 along with bivariate correlations with age. Correlations across Time 1 and Time 2 measures are shown in Table 3.

3.2.2 | Intentional action understanding

Initial analyses examined whether the likelihood of producing an anticipatory look to the AOI differed based on time point (Time 1, Time 2), reaching event (failed, successful), trial (1 through 5), and gender (male, female). Analyses were conducted using the Generalized Estimating Equations (GEE) procedure. GEE is appropriate here because it can account for the binary structure of the data (producing an anticipatory look or not on each trial) and can assess both within- and between-subjects effects. The model used a binomial outcome distribution with a logit link function and a robust estimator covariance matrix. Participants who contributed usable data on fewer than 50% of trials at each visit ($n = 10$) were excluded from analyses as this pattern suggests inattentiveness or poor data quality. Given the comparison by reaching event, infants who failed to contribute usable data for both reaching events were also excluded ($n = 4$). Following these exclusions, a sample of 100 infants remained.

TABLE 2 Descriptive data for Study 2

Variable	Mean	SD	Range	Correlation with age
Time 1				
1. Failed reach: prop anticipatory looks	0.14	0.28	0 to 1	0.033
2. Successful reach: prop anticipatory looks	0.21	0.32	0 to 1	−0.003
3. Bouts of triadic engagement	1.39	1.54	0 to 8	0.088
4. Face looks outside of triadic engagement	4.90	3.43	0 to 17	0.189[+]
Time 2				
1. Failed reach: prop anticipatory looks	0.36	0.35	0 to 1	0.248*
2. Successful reach: prop anticipatory looks	0.47	0.34	0 to 1	0.308**
3. Bouts of triadic engagement	2.56	1.86	0 to 8	0.306**
4. Face looks outside of triadic engagement	5.92	3.67	0 to 19	0.255**

**p < 0.01,
*p < 0.05,
[+]*p* < 0.10.

TABLE 3 Correlations across Time 1 and Time 2 measures of infant intentional action understanding and performance in the triadic engagement task

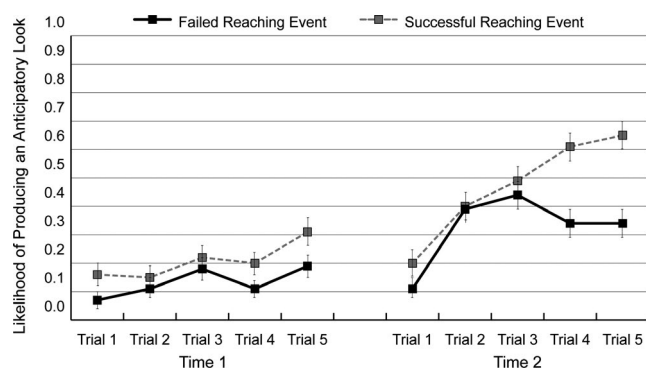|	Time 1 measures						Time 2 measures					
Time 1 measures	1	2	3	4	5	6	7	8	9	10	11	12
1. Failed reach: prop anticipatory looks		-0.749**	0.367**	-0.334**	0.100	-0.034	0.006	-0.214*	0.118	-0.205*	-0.055	-0.014
2. Failed reach: latency			-0.471**	0.437**	-0.091	0.051	0.098	0.098	-0.065	0.156	0.119	0.080
3. Successful reach: prop anticipatory looks				-0.914**	0.039	-0.128	0.007	0.042	0.250*	-0.238*	0.064	-0.009
4. Successful reach: latency;					-0.072	0.137	-0.130	0.030	-0.314**	0.293**	-0.106	-0.043
5. Bouts of triadic engagement						0.117	0.248*	-0.223*	0.308**	-0.278**	0.306**	0.255*
6. Face looks outside triadic							0.310**	-0.295**	0.045	-0.075	0.103	0.337**
Time 2 measures												
7. Failed reach: prop anticipatory looks								-0.748**	0.397**	-0.315**	0.253*	0.077
8. Failed reach: latency									-0.365**	0.410**	-0.236*	-0.164
9. Successful reach: prop anticipatory looks										-0.863**	0.279**	-0.018
10. Successful reach: latency;											-0.351**	-0.025
11. Bouts of triadic engagement												0.316**
12. Face looks outside triadic												

**$p < 0.01$,
*$p < 0.05$.

Estimated marginal means are plotted in Figure 2. Results revealed main effects of time point, $\chi^2(1, N = 1{,}759) = 31.83$, $p < 0.001$, and trial, $\chi^2(4, N = 1{,}759) = 71.40$, $p < 0.001$. As expected, the likelihood of producing an anticipatory look to the ball increased from Time 1 ($M = 0.16$) to Time 2 ($M = 0.38$). Anticipatory looks also increased across trials as infants saw the agent reach repeatedly. A significant interaction between time point and trial, $\chi^2(4, N = 1{,}759) = 10.86$, $p = 0.028$, indicated that the increase in anticipatory looking across trials was more pronounced at Time 2, $\chi^2(4, N = 900) = 84.70$, $p < 0.001$, than Time 1, $\chi^2(4, N = 859) = 29.48$, $p < 0.001$.

As expected, results also showed a main effect of reaching event, $\chi^2(1, N = 1{,}759) = 16.46$, $p < 0.001$: the likelihood of producing an anticipatory look to the ball was greater during the more basic successful ($M = 0.32$) than the more complex failed reach ($M = 0.20$). Results revealed an interaction of reaching event by trial, $\chi^2(4, N = 1{,}759) = 19.80$, $p = 0.001$, such that the differences in anticipatory looking during the failed versus successful reaching events were more pronounced in later trials. The interaction of time point, reaching event, and trial was non-significant ($p = 0.589$). There was no effect of gender ($p = 0.388$).

Similar analyses were conducted to examine whether infants' latency of looking to the AOI differed based on time point, trial, and gender. Latency analyses have the advantage of not relying on a specified anticipatory-looking criterion; however, they exclude trials on which infants never looked at the AOI (52.4% of failed, 31.0% of successful trials). Because the timing of the failed and successful reaching events differed substantially (e.g., total duration of the reach, latency of the actor's hand to the AOI), direct comparisons of latencies during the failed and successful events are uninterpretable. Thus, latency analyses were conducted separately for each event type. The GEE models tested used a normal outcome distribution with an identity link function and a robust estimator covariance matrix. Five infants were excluded from the failed reaching analyses for never looking at the ball on any trial, leaving a total of 95 infants.

Results revealed main effects of time point and trial for both the failed (time point: $\chi^2(1, N = 476) = 4.60$, $p = 0.032$; trial: $\chi^2(4, N = 476) = 16.61$, $p = 0.002$) and successful (time point: $\chi^2(1,$ $N = 690) = 27.86$, $p < 0.001$; trial: $\chi^2(4, N = 690) = 64.40$, $p < 0.001$) reaching events. For both events, infants looked faster at the ball at Time 2 and across trials. A significant interaction between time point and trial also emerged for both the failed ($\chi^2(4, N = 476) = 19.82$, $p = 0.001$) and successful ($\chi^2(4, N = 690) = 10.34$, $p = 0.035$) reaching events, showing that the decrease in latency across trials was steeper at Time 2 than Time 1.

3.2.3 | Triadic engagement

We used repeated-measures analysis of variance (ANOVA) to examine whether bouts of triadic engagement or face looks outside triadic engagement varied by time point and gender. Five infants with missing data from the triadic engagement task due to video recording problems were excluded from these analyses, leaving a sample of 109.

For bouts of triadic engagement, results showed significant main effects of both time point, $F(1, 107) = 43.69$, $p < 0.001$, $\eta_p^2 = 0.29$, and gender, $F(1, 107) = 16.98$, $p < 0.001$, $\eta_p^2 = 0.14$. Infants increased their participation in triadic engagement from Time 1 to Time 2 (Ms = 1.39, 2.56), and girls produced more bouts of triadic engagement than boys (Ms = 2.52, 1.52).
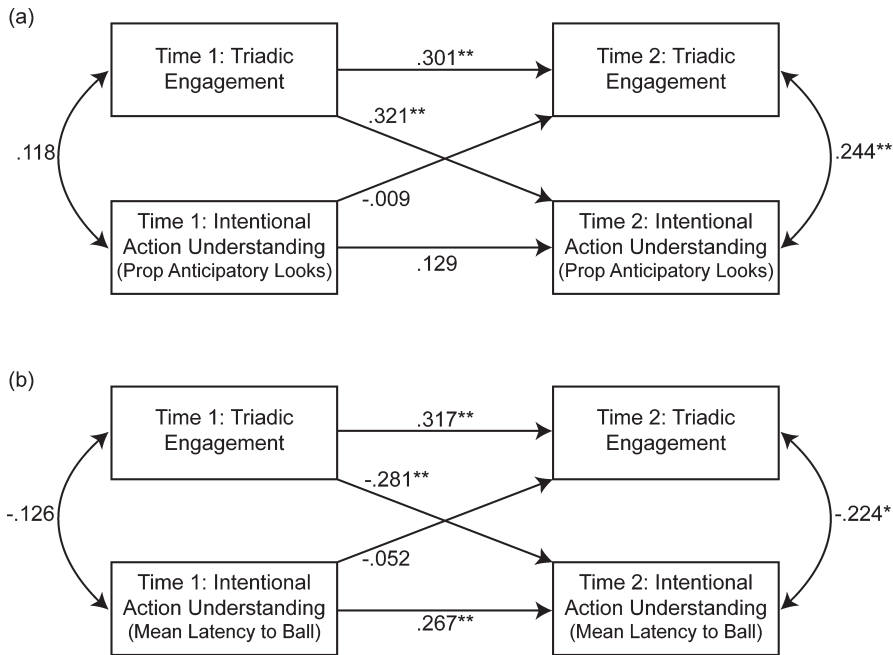
A similar pattern was observed for dyadic engagement as assessed by face looks outside triadic interaction. Analyses showed main effects of time point, $F(1, 107) = 5.21$, $p = 0.024$, $\eta_p^2 = 0.046$, and gender, $F(1, 107) = 4.40$, $p = 0.038$, $\eta_p^2 = 0.039$, with infants increasing the number of dyadic face looks from Time 1 to Time 2 (Ms = 4.90, 5.92), and girls producing more dyadic face looks than boys (Ms = 5.94, 4.81).

3.2.4 | Cross-lagged model analyses

To examine our central hypothesis regarding relations among triadic engagement and intentional action understanding across time, we tested a series of cross-lagged models in MPLUS (Muthén & Muthén, 1998–2017). We specified path models (see Figure 3) regressing Time 2 triadic engagement onto Time 1 intentional action understanding, and Time 2 intentional action understanding onto Time 1 triadic engagement. These cross-lagged effects were accompanied by autoregressive paths between the same constructs over time. All models were just-identified, so fit information is not provided. We first examined models using composite measures of performance across the failed and successful reaching tasks, followed by models examining each reaching event separately.

To create the composite measure of anticipatory looking, we divided the total number of anticipatory looks across failed and successful reaching trials by the total number of usable trials. To create the composite latency measure, we averaged the latency of looking to the ball on all usable trials across the failed and successful reaching events. Due to differences in the timing of these events, latencies were standardized using z-scores before averaging.

Infants who contributed usable data on at least 50% of trials at each time point and had usable data for both reaching events were

FIGURE 2 Estimated mean likelihood of producing an anticipatory look to the ball area of interest (±standard error) in the failed and successful reaching events as a function of trial (1 to 5) and time point (Time 1 vs. Time 2) in Study 2

FIGURE 3 Cross-lagged path models of triadic engagement and intentional action understanding in Study 2. The first model (a) uses the proportion of anticipatory looks to the ball area of interest (AOI) in the failed and successful reaching events as the measure of intentional action understanding. The second model (b) uses the mean latency of looking to the ball AOI across the failed and successful reaching events. **p < 0.01, *p < 0.05. Path coefficients are standardized

retained in the proportion analyses, leaving a sample of 100 infants. Latency analyses had the added requirement that infants look at the ball at least once at each time point. Eleven infants who failed to meet this criterion were excluded from the latency analyses, leaving a sample of 89. Finally, four infants with missing data from the triadic engagement task were retained in the sample because of the random nature of the recording problems that led to their missing data. Missing data were handled in MPLUS using maximum-likelihood estimation with robust standard errors.

Path results for the model using the proportion of anticipatory looks are illustrated in Figure 3a. First, results showed relative stability in individual differences in triadic engagement across time ($p = 0.003$). Intentional action understanding did not show the same stability ($p = 0.145$). Second, triadic engagement at Time 2 was positively associated with intentional action understanding at the same time point ($p = 0.008$). The same association was not observed at Time 1 ($p = 0.201$). Finally, triadic engagement at Time 1 predicted intentional action understanding at Time 2 ($p < 0.001$). In contrast, intentional action understanding at Time 1 did not contribute to triadic engagement at Time 2 ($p = 0.938$).

Results for the model using the mean latency of looking to the AOI are illustrated in Figure 3b. Analyses again showed relative stability in individual differences in triadic engagement across time ($p = 0.003$). The mean latency of looking at the AOI also showed stability from Time 1 to Time 2 ($p = 0.006$). Triadic engagement at Time 2 was again associated with intentional action understanding at the same time point ($p = 0.025$), but the same association was not observed at Time 1 ($p = 0.226$). Finally, triadic engagement at Time 1 again predicted intentional action understanding at Time 2 ($p < 0.001$). However, intentional action understanding at Time 1 did not contribute to triadic engagement at Time 2 ($p = 0.663$).

Additional cross-lagged models were tested to examine whether the relations between triadic engagement and intentional action understanding changed with the inclusion of Time 2 age or Time 1 levels of dyadic engagement as covariates. Although Time 2 age emerged as a significant predictor of Time 2 intentional action understanding (both ps < 0.05), neither of these covariates changed the significance of the critical paths from Time 1 triadic engagement to intentional action understanding or triadic engagement at Time 2 (all ps < 0.01).

Finally, because of the differences observed in infants' performance on the failed versus successful reaching events, we also examined separate cross-lagged models for each event type. Results largely replicated those in the composite analyses. Most critically, in all models, triadic engagement at Time 1 predicted intentional action understanding at Time 2 (all ps < 0.05). Intentional action understanding at Time 1 did not contribute to triadic engagement at Time 2 in any of the models (all ps > 0.341).

3.3 | Discussion

Study 2 results provide the first longitudinal evidence supporting the role of triadic engagement in the development of intentional action understanding (Barresi & Moore, 1996). Results showed that infants who produced more bouts of triadic engagement at 6–7 months demonstrated better performance on measures of failed and successful action understanding roughly three months later. Importantly, intentional action understanding at 6–7 months did not predict later triadic engagement. Thus, our data speak to the directionality of these relations and support the view that early triadic engagement promotes later intentional action processing and not the other way around. Finally, findings further support the special role of triadic over dyadic forms of interaction.

Three additional findings in the cross-lagged analyses are of note. First, although we saw stability of individual differences in infants' triadic engagement from Time 1 to Time 2 in all models, the stability in intentional action understanding was less consistent. This autoregressive path was significant in the model using the latency of looking to the ball, but not in the model using the proportion of anticipatory looks. In addition, significant relations across time were observed for the successful but not the failed reaching task (see Table 3). These inconsistencies may be due to the immature state of infants' action understanding at Time 1. Although infants are capable of representing basic reaching actions as goal-directed by this age (Woodward, 1998), infants' intentional action understanding is only just emerging. Thus, our relatively complex anticipatory-looking measures may not have captured meaningful variability in 6- to 7-month-olds' intentional action understanding—especially their understanding of failed actions.

Second, in none of the models did we replicate the concurrent relation between triadic engagement and intentional action understanding at Time 1. This may again be due to the challenging nature of our measures and the immature state of infants' knowledge at Time 1. This pattern may also imply that triadic engagement is involved in scaffolding advancements in intentional action processing across development, but is unrelated to action understanding in its earliest forms. We consider this further in the General Discussion 3.3.

Third, despite the clear mean-level differences in infants' patterns of anticipatory looking during the failed and successful reaching events, the relations between infants' triadic engagement tendencies and these different measures of intentional action understanding were largely similar: infants who produced more bouts of triadic engagement at Time 1 showed better processing of both failed and successful reaching actions at Time 2. Thus, although anticipating the goals of failed actions is significantly more challenging and appears developmentally later than the ability to generate predictions about successful actions (Brandone et al., 2014), the understanding of intentionality at the core of performance on both tasks maps onto earlier variability in triadic engagement. This pattern of results speaks against the possibility that experience in triadic engagement is uniquely related to a more robust form of intention understanding revealed only in failed action tasks. Instead, findings support a broader role of triadic engagement in the development of intentional action understanding.

4 | GENERAL DISCUSSION

The goal of the current studies was to investigate whether triadic engagement serves as a mechanism in the development of intentional action understanding during the first year of life. Four main findings emerged. First, infants' tendency to engage in bouts of triadic engagement during play was associated with their concurrent intentional action processing: In Study 1, 8- to 9-month-olds who engaged in more bouts of triadic engagement were better at prospectively reasoning about the goal of an intentional reaching

action. Second, Study 2 provides the first longitudinal evidence that early triadic engagement predicts later intentional action understanding: infants who showed more bouts of triadic engagement as 6- to 7-month-olds were better at reasoning about the goal of an intentional reaching action three months later. Third, the other longitudinal path—from early intentional action understanding to later triadic engagement—was not supported, implying that early triadic engagement facilitates later intention understanding and not the other way around. Finally, both studies support the unique contribution of triadic forms of interaction: dyadic engagement with the experimenter outside bouts of triadic interaction did not predict concurrent or later intentional action understanding.

The key role of triadic engagement observed here lends support to theoretical models proposing that triadic interaction is critical for infants' emerging social cognition (Barresi & Moore, 1996; Carpendale & Lewis, 2004; Hobson, 2002). Recall that Barresi and Moore (1996) propose that only in triadic interaction—when infants' actions and attentional states are aligned with those of another— can infants begin to compare the first-person experience of action execution with the third-person perspective of action observation. By explicitly comparing their own actions and attention with the matched actions and attention of a social partner during triadic engagement, infants gradually gain insight into their own and others' intentionality.

Consistent with this account, the links between triadic engagement and intentional action processing observed here may be interpreted as causal in nature. That is, infants who participate in triadic engagement more frequently earlier in development have more opportunities to match their own actions and attentional states with those of others, and thus show more advanced understanding of others' intentional actions. The longitudinal evidence in Study 2 offers support for this position. Nevertheless, given the correlational nature of these studies, strong claims about causality must be limited. Although accumulating experience in triadic interaction across infancy may propel the development of intention understanding, it remains possible that a third variable is responsible for both early triadic engagement and later intention understanding. Studies implementing an experimental design (e.g., manipulating infants' experience in triadic engagement) are needed to firmly test a causal claim.

Our findings also highlight several open questions about infants' emerging social-cognitive abilities. One question concerns the scope of the observed link between triadic engagement and intentional action processing. Our findings support the contribution of triadic engagement to performance on a relatively challenging task where infants need to make online predictions about actions—including a complex failed action in which the actor's goal is never achieved. It remains to be seen whether the role of triadic engagement is unique to these more complex forms of understanding or whether it also supports infants' learning about more basic social-cognitive concepts. Evidence of early competence in reasoning about the intentionality of actions has led some to propose that infants are born with a computational system that provides a skeletal framework for reasoning about intentional actions (Biro & Leslie, 2007; Gergely &

Csibra, 2003). Such a system may support infants' nascent reasoning about basic goal-directed actions, with experience in triadic interaction helping to enrich or transform this system. The fact that triadic engagement and intentional action understanding were unrelated at 6–7 months may be consistent with this possibility. However, this conclusion must be tempered by infants' relatively poor performance in the intentional action tasks at this age. Studies examining links between triadic engagement and other forms of intentional action processing at varying levels of difficulty are needed to further explore this idea.

A second question is what explains the individual differences in triadic engagement observed in the current studies. At 6–7 months, infants varied considerably in their levels of triadic engagement, which had implications for their later intentional action understanding. However, the source of this variability remains unknown. One possibility is that these differences stem from inherent or temperamental characteristics of the infants that make them more or less likely to initiate or join in on triadic opportunities. Variability in attention-related constructs, such as duration of orienting, inhibition, or distractibility may play a role (Morales et al., 2000). Variability in more socially oriented constructs, such as sociability, positive emotional reactivity, or approach toward pleasurable activities, may also play a role (Todd & Dixon, 2010; Vaughan et al., 2003). Indeed, there is some evidence that infants' "socially observant temperament" predicts concurrent intentional action processing (Dunphy-Lelii et al., 2014) and later theory of mind (Brink et al., 2015).

Another possibility is that variability in early triadic engagement stems from a history of social interactions between infants and familiar social partners. Preliminary support for this view comes from micro-analyses of infant–caregiver interactions showing that when caregivers follow and reinforce an infant's focus of attention on an object, infants are more likely to enter episodes of joint engagement around that object (Mendive, Bornstein, & Sebastian, 2013). Caregivers' scaffolding behaviors (e.g., directing attention to a toy) at 9 months have also been shown to be related to infants' initiation of joint engagement at 12 months (Vaughan et al., 2003). Thus, it is possible that the frequency and quality of infant–caregiver interactions from early in infancy impact infants' emerging triadic engagement tendencies. More work is needed to systematically unpack these early caregiver behaviors and pinpoint how they shape infants' social cognition (see Hofer, Hohenberger, Hauf, & Aschersleben, 2008; Licata et al., 2014, for related evidence of links between caregiver behavior and infants' action understanding).

A final question concerns how to integrate this new evidence on the role of triadic engagement with theoretical accounts that emphasize infants' own experience as intentional agents (e.g., Gredebäck & Falck-Ytter, 2015; Woodward et al., 2009). There is now substantial evidence that infants' own action production influences their action understanding (see Gerson & Woodward, 2010, for a review). However, these findings are not incompatible with the idea that triadic engagement also contributes to the development of intentional action understanding. According to Barresi and Moore (1996), two conditions must be met to construct an understanding of intentional relations. First, infants' own intentional actions on an object must co-occur with a social partner's comparable actions on the same object. Second, when this alignment occurs, infants must notice and attend to the alignment. Thus, this account requires that infants have both the motor capacity to engage in object-directed actions that match their partner's and the social capacity to share attention and action when this situation arises. Research currently supports the importance of both motor and social mechanisms independently; however, a crucial goal for future research should be to investigate whether and how these mechanisms work together to facilitate infants' intentional action understanding.

It is important to also consider the following limitations on the current studies. First, infants' intentional action processing at 6–7 months was relatively poor. Thus, it is difficult to interpret the concurrent and longitudinal relations involving this measure. Second, during the second visit of Study 2, infants varied widely in age; although we controlled for Time 2 age statistically in analyses, there is no way to fully control for the breadth of changes occurring during this developmental period. Third, we used a single measure of triadic engagement derived from infants' interaction with an unfamiliar researcher. Although we deliberately assessed triadic engagement in a standardized interaction with an experimenter to eliminate caregiver interaction style as a factor in infants' behavior, we do not know the extent to which these differences in triadic engagement map onto patterns of engagement with others, including familiar caregivers. Finally, as discussed previously, the correlational nature of these studies limits our ability to make causal claims about the role of triadic engagement in supporting intentional action understanding.

Despite these limitations, the current studies provide important new insight into how infants use their rich social context to build an understanding of intentional action. Our results demonstrate that infants' early tendency to engage in triadic interactions predicts their later intentional action understanding. These findings imply that infants' experiences in triadic interactions with social partners create powerful opportunities for learning about intentionality, likely paving the way for the development of a more complex, mentalistic understanding of the social world.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on the Open Science Framework, https://doi.org/10.17605/OSF.IO/Y8UPZ.

REFERENCES

Adolph, K. E., Berger, S. E., & Leo, A. J. (2011). Developmental continuity? Crawling, cruising, and walking. *Developmental Science*, 14, 306–318. https://doi.org/10.1111/j.1467-7687.2010.00981.x

Bakeman, R., & Adamson, L. B. (1984). Coordinating attention to people and objects in mother-infant and peer-infant interaction. *Child Development*, 55, 1278–1289. https://doi.org/10.2307/1129997. Retrieved from https://www.jstor.org/stable/1129997

Barresi, J., & Moore, C. (1996). Intentional relations and social understanding. *Behavioral and Brain Sciences*, 19, 107–122. https://doi.org/10.1017/S0140525X00041790

Biro, S., & Leslie, A. (2007). Infants' perception of goal-directed actions: Development through cues-based bootstrapping. *Developmental Science*, 10, 379–398. https://doi.org/10.1111/j.1467-7687.2006.00544.x

Brandone, A. C. (2015). Infants' social and motor experience and the emerging understanding of intentional actions. *Developmental Psychology*, 51, 512–523. https://doi.org/10.1037/a0038844

Brandone, A. C., Horwitz, S., Wellman, H. M., & Aslin, R. N. (2014). Infants' goal anticipations during failed and successful reaching actions. *Developmental Science*, 17, 23–34. https://doi.org/10.1111/desc.12095

Brandone, A. C., & Wellman, H. M. (2009). You can't always get what you want: Infants understand failed goal-directed actions. *Psychological Science*, 20, 85–90. https://doi.org/10.1111/j.1467-9280.2008.02246.x

Brink, K. A., Lane, J. D., & Wellman, H. M. (2015). Developmental pathways for social understanding: Linking social cognition to social contexts. *Frontiers in Psychology*, 6, 719. https://doi.org/10.3389/fpsyg.2015.00719

Brune, C. W., & Woodward, A. L. (2007). Social cognition and social responsiveness in 10-month-old infants. *Journal of Cognition and Development*, 8, 133–158. https://doi.org/10.1080/15248370701202331

Cannon, E. N., & Woodward, A. L. (2012). Infants generate goal-based action predictions. *Developmental Science*, 15, 292–298. https://doi.org/10.1111/j.1467-7687.2011.01127.x

Cannon, E. N., Woodward, A. L., Gredebäck, G., von Hofsten, C., & Turek, C. (2012). Action production influences 12-month-old infants' attention to others' actions. *Developmental Science*, 15, 35–42. https://doi.org/10.1111/j.1467-7687.2011.01095.x

Carpendale, J. I., & Lewis, C. (2004). Constructing an understanding of mind: The development of children's social understanding within social interaction. *Behavioral and Brain Sciences*, 27, 79–96. https://doi.org/10.1017/S0140525X04000032

Carpenter, M., Nagell, K., Tomasello, M., Butterworth, G., & Moore, C. (1998). Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development*, 63(4). https://doi.org/10.2307/1166214

Datavyu Team. (2014). Datavyu: A video coding tool. Databrary Project, New York University. Retrieved from http://datavyu.org

Daum, M. M., Prinz, W., & Aschersleben, G. (2011). Perception and production of object-related grasping in 6-month-olds. *Journal of Experimental Child Psychology*, 108, 810–818. https://doi.org/10.1016/j.jecp.2010.10.003

Dunphy-Lelii, S., LaBounty, J., Lane, J. D., & Wellman, H. M. (2014). The social context of infant intention understanding. *Journal of Cognition and Development*, 15, 60–77. https://doi.org/10.1080/15248372.2012.710863

Falck-Ytter, T., Gredebäck, G., & von Hofsten, C. (2006). Infants predict other people's action goals. *Nature Neuroscience*, 9, 878–879. https://doi.org/10.1038/nn1729

Gaffan, E. A., Mertins, C., Healy, S., & Murray, L. (2010). Early social experience and individual differences in infants' joint attention. *Social Development*, 19, 369–393. https://doi.org/10.1111/j.1467-9507.2008.00533.x

Gallese, V., Rochat, M., Cossu, G., & Sinigaglia, C. (2009). Motor cognition and its role in the phylogeny and ontogeny of action understanding. *Developmental Psychology*, 45, 103–113. https://doi.org/10.1037/a0014436

Gergely, G., & Csibra, G. (2003). Teleological reasoning in infancy: The naive theory of rational action. *Trends in Cognitive Sciences*, 7, 287–292. https://doi.org/10.1016/S1364-6613(03)00128-1

Gerson, S., & Woodward, A. L. (2010). Building intentional action knowledge with one's hands. In S. P. Johnson (Ed.), *Neoconstructivism: The new science of cognitive development* (pp. 295–313). New York, NY: Oxford University Press.

Gerson, S. A., & Woodward, A. L. (2013). Learning from their own actions: The unique effect of producing actions on infants' action understanding. *Child Development*, 85, 264–277. https://doi.org/10.1111/cdev.12115

Gredebäck, G., & Falck-Ytter, T. (2015). Eye movements during action observation. *Perspectives on Psychological Science*, 10, 591–598. https://doi.org/10.1177/1745691615589103

Gredebäck, G., Johnson, S., von Hofsten, C. (2009). Eye tracking in infancy research. *Developmental Neuropsychology*, 35, 1–19. https://doi.org/10.1080/87565640903325758

Henderson, A. M., & Woodward, A. L. (2011). "Let's work together": What do infants understand about collaborative goals? *Cognition*, 121, 12–21. https://doi.org/10.1016/j.cognition.2011.05.008

Hobson, P. (2002). *The cradle of thought: Exploring origins of thinking*. New York, NY: Oxford University Press.

Hofer, T., Hohenberger, A., Hauf, P., & Aschersleben, G. (2008). The link between maternal interaction style and infant action understanding. *Infant Behavior and Development*, 31, 115–126. https://doi.org/10.1016/j.infbeh.2007.07.003

Kanakogi, Y., & Itakura, S. (2011). Developmental correspondence between action prediction and motor ability in early infancy. *Nature Communications*, 2, 341. https://doi.org/10.1038/ncomms1342

Krogh-Jespersen, S., Liberman, Z., & Woodward, A. L. (2015). Think fast! The relationship between goal prediction speed and social competence in infants. *Developmental Science*, 18, 815–823. https://doi.org/10.1111/desc.12249

Licata, M., Paulus, M., Thoermer, C., Kristen, S., Woodward, A., & Soidan, B. (2014). Mother–infant Interaction quality and infants' ability to encode actions as goal-directed. *Social Development*, 23, 340–356. https://doi.org/10.1111/sode.12057

Meltzoff, A. N. (1995). Understanding the intentions of others: Re-enactment of intended acts by 18-month-old children. *Developmental Psychology*, 31, 838–850. https://doi.org/10.1037/0012-1649.31.5.838

Mendive, S., Bornstein, M. H., & Sebastian, C. (2013). The role of maternal attention-directing strategies in 9-month-old infants attention joint engagement. *Infant Behavior and Development*, 36, 115–123. https://doi.org/10.1016/j.infbeh.2012.10.002

Morales, M., Mundy, P., Delgado, C. E. F., Yale, M., Neal, R., & Schwartz, H. K. (2000). Gaze following, temperament, and language development in 6-month-olds: A replication and extension. *Infant Behavior and Development*, 23, 231–236. https://doi.org/10.1016/S0163-6383(01)00038-8

Muthén, L. K., & Muthén, B. O. (1998–2017). *Mplus user's guide* (8th edn.). Los Angeles, CA: Muthén & Muthén.

Papp, G., & Fillipin, L. (2014). *The TobiiPlus module*. Retrieved from http://psy.ck.sissa.it

R Core Team. (2017). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieve from https://www.R-project.org/

Sommerville, J. A., & Woodward, A. L. (2005). Pulling out the intentional structure of action: The relation between action processing

and action production in infancy. *Cognition*, *95*, 1–30. https://doi.org/10.1016/j.cognition.2003.12.004

Sommerville, J. A., Woodward, A. L., & Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. *Cognition*, *96*, B1–B11. https://doi.org/10.1016/j.cognition.2004.07.004

Striano, T., & Bertin, E. (2005). Social-cognitive skills between 5 and 10 months of age. *British Journal of Developmental Psychology*, *23*, 559–568. https://doi.org/10.1348/026151005X26282

Striano, T., Stahl, D., & Cleveland, A. (2009). Taking a closer look at social and cognitive skills: A weekly longitudinal assessment between 7 and 10 months of age. *European Journal of Developmental Psychology*, *6*, 567–591. https://doi.org/10.1080/17405620701480642

Todd, J. T., & Dixon, W. E. (2010). Temperament moderates responsiveness to joint attention in 11-month-olds. *Infant Behavior and Development*, *33*, 297–308. https://doi.org/10.1016/j.infbeh.2010.03.007

Tomasello, M. (1999). Having intentions, understanding intentions and understanding communicative intentions. In P. D. Zelazo, J. W. Astington & D. R. Olson (Eds.), *Developing theories of intention: Social understanding and self-control* (pp. 63–75). Mahwah, NJ: Lawrence Erlbaum Associates.

Trevarthen, C., & Hubley, P. (1978). Secondary intersubjectivity: Confidence, confiding and acts of meaning in the first year. In A. Lock (Ed.), *Action, gesture, and symbol: The emergence of language* (pp. 183–226). New York, NY: Academic Press.

Vaughan, A., Mundy, P., Block, J., Burnette, C., Delgado, C., Gomez, Y., … Pomares, Y. (2003). Child, caregiver, and temperament contributions to infant joint attention. *Infancy*, *4*, 603–616. https://doi.org/10.1207/S15327078IN0404_11

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, *69*, 1–34. https://doi.org/10.1016/S0010-0277(98)00058-4

Woodward, A. L., & Guajardo, J. J. (2002). Infants' understanding of the point gesture as an object-directed action. *Cognitive Development*, *178*, 1061–1084. https://doi.org/10.1016/S0885-2014(02)00074-6

Woodward, A. L., Sommerville, J. A., Gerson, S., Henderson, A. M. E., & Buresh, J. (2009). The emergence of intention attribution in infancy. In B. Ross (Ed.), *The psychology of learning and motivation* (Vol. *51*, pp. 187–222). Burlington, MA: Academic Press.