

The Development of Intention Understanding in the First Year of Life: An Exploration of  
Infants' Understanding of Successful vs. Failed Intentional Actions

by

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## **ABSTRACT**

This dissertation explored the questions of when and how infants develop an understanding of intention—that is, an understanding of human behavior as guided by subjective internal states that underlie and are separate from actions and objects in the world. Failed action understanding was used as a marker of intention understanding because, unlike in the case of successful actions, understanding failed actions requires recognizing that the observed pattern of movement is distinct from the intention that motivates it.

To explore the development of intention understanding in the first year of life, two key studies examined an understanding of successful- versus failed-reaching actions. Study 1 used a habituation design to assess both when infants (8-, 10-, and 12-month-olds) understand that a failed action is intentional and whether an understanding of successful actions precedes an understanding of failed actions. Study 2 extended this work to explore the process by which 8- and 10-month-olds develop an understanding of intention. Eye-tracking methodology was used to examine how infants process and predict the goals of ongoing successful and failed reaching actions. Moreover, performance was explored in relation to parent-report measures of infants' social and motor behaviors.

Three central findings emerged. First, already within the first year of life (by 10 months), infants understand and can predict the goal of a failed-reaching action. Second, during the course of development, understanding successful actions precedes understanding failed actions. Third, failed (but not successful) action understanding is strongly associated with infants' tendency to initiate joint attention and their ability to locomote independently.

Overall, results from this dissertation support a developmental picture wherein a rudimentary understanding of action as motivated by subjective internal states emerges during the first year of life from an antecedent understanding of action that does not go



deeper than the surface relations between agents and objects. Preliminary evidence is consistent with the hypothesis that the emergence of this understanding of intention is related to experiences in joint-attentive social interactions that occur with increasing frequency as infants learn to crawl and walk. Developmental mechanisms and implications of an understanding of intention are discussed.

## CHAPTER I

### *INTRODUCTION*

A hallmark of human cognition is the ability to transcend the information provided by the behavior stream and make inferences about the underlying causes of human action. We see the actions of others not only as physical movements through space, but also as behaviors structured by internal mental states such as intentions, thoughts, desires, and beliefs. Indeed, the success of human social interaction rests upon considerations of intention. A critical developmental question is, thus, when and how do children come to perceive the motions of others as guided by intentions? This question is functionally and theoretically important because the ability to infer intentions is essential for many aspects of cognitive, social, and linguistic development, and this ability marks infants' first step toward a theory of mind (e.g., Wellman, Lopez-Duran, LaBounty, & Hamilton, 2008) and culture (e.g., Tomasello, 1999).

The goal of this dissertation is to explore both *when* and *how* infants develop an understanding of intention during the first year of life. To do so, I focus on infants' reasoning about failed human actions. Reasoning about the goal of a failed action provides a diagnostic test for understanding intention because in a failed action the observed pattern of motion is distinct from its intention—the subjective internal state motivating the action. Consider the example of a basketball player who, despite his intention to put the ball through the hoop, misses and bounces the ball off of the rim. As this example illustrates, in the case of a failed action, the observed sequence of events (e.g., the ball bouncing off of the rim) is inconsistent with the actor's intention (e.g., shooting the ball through the hoop). Because the goal of a failed action is not apparent in its overt physical outcome, reasoning about the goal of a failed action would not be possible without at least a rudimentary understanding of intentions as distinct from the actions they motivate. Therefore, to investigate the development of intention understanding, in this dissertation, I examine infants' reasoning about failed actions.

Two key studies examine the development of an understanding of successful and failed intentional actions in infants between the ages of 8 and 12 months. In Study 1, a habituation study examining 8-, 10-, and 12-month-olds' understanding of directly comparable successful and failed reaching actions, I focus on two central questions. First, when do infants perceive failed actions as guided by intentions that are not manifested in action? Does this ability emerge during the first year of life? Second, what is the relationship between reasoning about successful and failed actions? Does understanding failed actions (i.e., actions in which there is a mismatch between the underlying intentions and observed movements) represent a developmental advance over understanding directly comparable successful actions (i.e., actions in which underlying intentions are manifest in the observed actions)?

Study 2 moves beyond the results of Study 1 to explore the *process* by which infants learn about intentional actions. How do infants begin to discover the hidden intentions underlying human action and how is this developmental milestone related to other contemporaneous developmental achievements? In this study, I use eye-tracking methodology to examine infants' processing and learning about ongoing successful- and failed-reaching actions. In addition, Study 2 includes a parent-report measure of infant motor behaviors (e.g., crawling, walking, means-end behavior production) and social behaviors (e.g., pointing, imitating, gaze following, joint attention) presumed to be related to the development of intention understanding (e.g., Bretherton, 1991; Campos et al., 2000; Tomasello, 1995). Using this measure, I explore whether the behaviors infants are producing outside of the laboratory are related to their understanding of intention as demonstrated in the experimental task.

Overall, this dissertation sheds light on the emergence of an intentional understanding of behavior in the following ways: (1) by providing evidence for infants' understanding of failed actions in the first year of life; (2) by empirically supporting the hypothesis that an intentional understanding of human action represents a developmental advance over an antecedent action- or object-based understanding of human behavior; and (3) by offering insight into the mechanisms by which infants learn about intentional actions.

## Background and Literature Review

### Defining Intention

Philosophers and psychologists have long been interested in the concepts of intention and intentionality. Indeed, there is a vast philosophical literature and debate on the precise nature of intentions, intentional actions, and intentionality (e.g., Brentano, 1874; Dennett, 1987; Malle et al., 2001; Searle, 1983). Thus, before I review the literature on infants' understanding of intentions, it is important to first define my terms.

For the purpose of this dissertation, *intentions* refer to subjective internal states that underlie and are separate from the actions that arise from them. There are at least two key components of this definition that are important to highlight. The first is that intentions are internal states that are, by definition, not directly perceivable. Although intentions are “about” or directed toward objects or events in the world (e.g., Brentano, 1874/1970; Dennett, 1987), intentions are not objects or events. Consider the example of an individual who desires and plans to purchase a necklace featured in a jewelry catalog. Although this intention is directed toward and intimately linked with the necklace in the catalog, the intention is not the necklace itself. The intention is the internal desire for and plan to acquire the necklace. The necklace itself is what I will refer to as a *goal*—a desired physical object or physical state in the world that is potentially directly perceivable. Thus, the first key component of this definition of is that intentions are distinct from the goals they are directed toward.

The second aspect of the definition of intention that is important to highlight is that intentions are separate from the overt movements or actions that arise from them (i.e., *intentional actions*). Some simple intentional actions (e.g., grasping a ball or pushing a button) can transparently enact their intentions. In these examples, the desire to grasp the ball or push the button is essentially evident in the overt achieved physical outcome of the action. However, the intention and the action are nonetheless distinct. Moreover, the relation between intentions and actions is not always this clear. Consider the action of poking a needle into someone's arm. This action could arise from the intention to heal, as in the case of a doctor administering an immunization, or from the intention to harm, as in the case of a sadist injuring his victim. Likewise, the same intention, such as the intention to heal, could give rise to any number of different possible actions, ranging

from speaking with a troubled patient to performing invasive surgery (example adapted from Baldwin & Baird, 1999). Intentions can even exist in the absence of action, as in the case of an individual with a secret plan that is never executed. Thus, although intentions and actions are deeply intertwined, intentions and intentional actions are nonetheless distinct.

Given this definition of intention, the question motivating this dissertation can be framed as follows: When and how do infants develop an understanding of human behavior as guided by subjective internal states that underlie and are separate from actions and objects in the world? Researchers have taken a variety of theoretical approaches to these questions. In the following section, I will review existing accounts of the development of intention understanding.

### **Theoretical Accounts of the Development of Intention Understanding**

Within the question of the development of intention understanding there are at least two fundamental issues. First is the question of *when* an understanding of intention develops. Some theorists have proposed that an essential kernel of intention understanding is available from the very outset of infants' conceptual life (e.g., Premack, 1990; Reddy, 1991; Trevarthen, 1979). For example, Premack (1990) proposed that infants are born with a system for interpreting actions as intentional whenever the actor displays self-propelled motion. On this view, infants interpret actions as intentional from the start and experience serves only to enable infants to construct increasingly refined and appropriate inferences regarding an actor's specific intentions.

Many theorists offer a contrasting account—that infants experience a relatively protracted period during which they observe and interact with others but are not capable of drawing inferences regarding the subjective internal states underlying others' actions (e.g., Barresi & Moore, 1996; Baron-Cohen, 1995; Leslie, 1994; Gergely & Csibra, 2003; Tomasello, 1995; Wellman & Phillips, 2001; Woodward, 2009). Within this theoretical position, there is vast variability regarding the timing of this developmental achievement and the mechanism responsible. However, researchers from this perspective agree that infants do not understand intention from birth.

The question of when an understanding of intention develops has also been considered from the perspective of phylogeny (e.g., Call & Tomasello, 2008; Cheney &

Seyfarth, 1990; Premack & Woodruff, 1978; Tomasello & Call, 1997). In particular, researchers have explored to what extent the capacity to infer the subjective internal states of others is shared with nonhuman primates. The finding that some of the same components of action comprehension present early in human development are shared with other species (for a review, see Rosati, Hare, & Santos, 2009; Wellman & Brandone, 2009) has led many to argue that even nonhuman primates understand others' behavior in terms of intentions (Call & Tomasello, 2008; Hauser & Wood, 2009; Rosati et al., 2009). Nevertheless, others claim that existing research does not provide sufficient evidence of nonhuman primates' ability to reason beyond observable features and infer mental states (Povinelli & Vonk, 2003, 2006).

A related yet distinct issue is the question of *by what mechanism* an understanding of intention develops. Some theorists stress the role of innate factors. Several variants of this general proposal have been formulated—each positing that intention understanding is explained by innately based, domain-specific systems or modules that exist independent of experience (Baron-Cohen, 1995; Biro & Leslie, 2007; Gergely & Csibra, 2003; Leslie, 1994; Luo & Baillargeon, 2005; Premack, 1990). For example, Leslie (1994) and Baron-Cohen (1995) suggest that the human brain is innately endowed with modules specifically designed for interpreting others' behavior. These modules develop according to a biologically based timetable—not according to experience. In an alternative proposal, Gergely & Csibra (2003) argue that infants are equipped with an evolved inferential system, which they call the 'teleological stance', for generating goal-directed action representations. Still others have proposed that the mirror neuron system—a system of sensory-motor neurons that fire during both action production and perception (in human and nonhuman primates)—provides an innate neural mechanism for understanding intention (Ferrari, Rozzi, & Fogassi, 2005; Fogassi et al., 2005; Grezes & Decety, 2001; Iacoboni et al., 2005; Rizzolatti, Fogassi, & Gallese, 1996). Although these positions vary considerably with respect to the nature of the core system responsible, each emphasizes the role of innate factors or systems in evaluating intention.

In contrast, others have proposed a more constructivist account that points to learning and experience as the mechanisms underlying the development of intention understanding (Barresi & Moore, 1996; Meltzoff & Moore, 1994; Moore, 2006;

Tomasello, 1995; Wellman & Phillips, 2001; Woodward, 2009). The strongest claim for the experience-based account of intention understanding comes from Woodward and colleagues (e.g., Brune & Woodward, 2007; Sommerville et al., 2005; Woodward, 2009). Woodward argues that infants' intention understanding is powerfully influenced by their own experience as intentional agents. As infants become able to organize their own actions with respect to goals, they also become able to see intentional structure in others' actions. Thus, infants' first-person agentic experiences provide them with particularly strong insights into others' intentions. Others (e.g., Wellman & Phillips, 2001) highlight how infants' analyses of the overt intentional actions performed by others could also constitute a critical source of information for the development of intentional understanding. Finally, Moore and colleagues have emphasized the role of experience in joint-attentive, triadic social interactions (in which infants share attention with others on objects) for learning about others' intentions (e.g., Barresi & Moore, 1996; Moore, 2006). Despite the differences in these positions, overall, on this view, intention understanding is constructed through learning and experience.

An interesting theoretical proposal that crosscuts these dimensions is that a true understanding of intention as a subjective internal state is preceded by a simplified action- or object-based understanding of human behavior (e.g., Gergely & Csibra, 2003; Wellman & Phillips, 2001; Woodward, 1998). On this view, infants first understand goal-directed action without attributing intentional mental states to the actor's mind. One constructivist hypothesis within this perspective is that infants may understand human actions as organized by relations between agents and their goals without attributing intentions to those agents (e.g., Woodward, 1998; Wellman & Phillips, 2001). To illustrate, consider the action of an individual reaching toward and grasping a toy. This action could be represented in terms of its directedness toward the toy or the relation between the agent and her goal (e.g., she grasped the toy) without reference to the agent's internal state (e.g., her desire and plan to retrieve the toy). This understanding of the goal-directedness of human action may serve as a stepping-stone along the path to an understanding of intention.

Gergely and Csibra (2003) offer a distinct yet related proposal—that intentional, mentalistic accounts of human behavior are conceptually and developmentally derived

from a non-mentalistic, reality-based, action interpretation system, which they call the ‘teleological stance’. They argue that teleological action explanations are based on directly perceptible action and goal information as well as an innate principle of rational action which specifies that (1) actions function to bring about future goal states and that (2) goal states are realized by the most rational action available to the actor within a given context. Gergely and Csibra argue that infants use this principle to represent the goal-directedness of action before they are able to represent intentional mental states.

In sum, although there are a variety of different theoretical accounts for the development of intention understanding, questions remain as to precisely when and how infants understand intentions as subjective internal states. In the remainder of this section, I will review the existing evidence on infants’ (and, where relevant, nonhuman primates’) understanding of goals and intentions. To preview, I will begin with a brief discussion of infants’ intention understanding as revealed in their spontaneous social behavior. I will then discuss empirical research demonstrating infants’ ability to reason about successful goal-directed actions during the first year of life. Next, I will review existing evidence on infants’ reasoning about incomplete and failed actions, and the ways in which this evidence falls short of demonstrating true intention understanding during the first year of life. Finally, I will discuss the contribution of this dissertation to the study of the emergence of intention understanding during infancy.

### **Evidence from Spontaneous Social Behavior**

Infants engage in spontaneous social behavior from birth. Young infants are intensely interested in other people and they engage in well-structured dyadic interactions, such as smiling or vocalizing in response to their mother’s smiles and vocalizations, from the first few months of life (Cohn & Tronick, 1987; Hains & Muir, 1996; Jaffe et al., 2001; Tronick, 1989). By the end of the first year, infants begin to incorporate outside entities, such as objects, in their interactions with others. These triadic interactions often involve sharing attention to objects with an adult (Bakeman & Adamson, 1984), following an adult’s gaze to an object (Butterworth & Grover, 1990; Carpenter, Nagell, & Tomasello, 1998; Moore & Corkum, 1998; Scaife & Bruner, 1975), and directing an adult’s attention via pointing and other communicative gestures (Bates et al., 1979; Carpenter et al., 1998; Liszkowski, Carpenter, Henning, Striano & Tomasello, 2004).



Some researchers have taken these social behaviors as evidence that infants appreciate others' intentions (Bretherton, 1991; Tomasello, 1995, 1999). On this view, when infants follow others' gaze shifts, point to objects, and engage in shared attention, their actions serve as behavioral manifestations of an underlying awareness that people possess subjective internal states that influence and are influenced by objects and events in the environment. However, others have identified problems with assuming that infants' social behaviors are direct evidence for their intention understanding. On one hand, infants' social responses may lead to *overestimation* of their social knowledge because they can often be explained by lower-level factors, reinforcement learning, or adults' management of infants' actions. For example, infants may follow gaze based on a history of reinforcement for doing so (i.e., when they gaze-follow they often see an interesting sight) or by simply matching a head turn without understanding the intentional nature of visual experience (Corkum & Moore, 1998). On the other hand, reliance on spontaneous social behaviors as evidence can also lead to *underestimation* of infants' intentional understanding depending on the criteria used and the complexity of the social behavior involved (Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009).

In sum, although evidence from infants' spontaneous social behaviors is revealing, because these behaviors are driven by many factors, it is difficult to draw conclusions about whether or not a true understanding of intention underlies infants' social behaviors.

### **Experimental Evidence from Reasoning about Successful Actions**

In addition to the evidence from infants' spontaneous social behaviors, evidence from experimental studies has helped to more precisely probe infants' understanding of goals and intentions. Experimental evidence comes in at least two forms: (1) visual attention studies—which measure infants' passive observation of others; and (2) active-interactive paradigms—which measure infants' active interactions with others. Existing research on infants' reasoning about successful actions has generally used visual attention methods and, in particular, visual habituation.

The habituation method is based on infants' natural tendency to increase their visual attention to stimuli that are novel or that violate their expectations. In habituation studies examining infants' understanding of intention, researchers typically contrast the surface features of successful goal-directed actions (e.g., their physical patterns of

motion) with their deeper, principle-relevant aspects (e.g., their goals/intentions). The underlying hypothesis is that if infants interpret an observed action in terms of its goal, then following habituation they will look longer at events in which that goal is changed; in contrast, if infants interpret an observed action in terms of its surface features, then following habituation they will look longer at events in which those surface features have changed. Thus, infants' patterns of looking can reveal the structure of their event representations and, critically, their understanding of goals and intentions.

A likely prerequisite to the ability to discern intentions in behavior is the ability to parse continuous action into units that coincide with an actor's initiation and completion of intentions. Baldwin, Baird, Saylor, & Clark (2001) found that, during the first year of life, infants are sensitive to this intentional structure of successful human actions. In this study, Baldwin and colleagues familiarized 10- to 11-month-olds with sequences of continuous everyday intentional actions. For example, in one action sequence, a woman notices a towel on the floor, reaches for and grasps it, then moves toward and places it on a towel rack. Following habituation, infants were shown test sequences that were interrupted by pauses. In one type of test video, pauses occurred in the midst of the actor's pursuit of her goals (e.g., in the midst of grasping the towel). In the other, pauses occurred at goal boundary points (e.g., following the successful completion of the grasp). Baldwin and colleagues reported that infants showed renewed interest in test videos in which goal-directed actions were disrupted, but did not show renewed interest in test videos in which actions were paused at goal boundary points. These findings demonstrate that infants readily detect disruptions of the structure in goal-directed actions and spontaneously parse dynamic behavior at junctures coinciding with boundaries between intentions.

In addition to this ability to detect structure that is relevant for drawing inferences about intentions, another crucial component of intention understanding is the ability to attend selectively to aspects of an action that are related to an actor's goals. In a classic study, Woodward (1998) explored this question by asking if infants encode reaching actions in terms of the relation between the agent and her goal ("She grasped the bear") rather than in terms of the strictly physical properties of the arm's motion. Woodward habituated 5- and 9-month-olds to an event in which an arm reached consistently for one

of two toys (e.g., she reached for the bear on the left, not the ball on the right). Following habituation, infants saw two test events in which the locations of the two toys had changed (e.g., the bear on the right, the ball on the left). In one event, the spatiotemporal path of the arm remained the same whereas its target object was changed (e.g., she reached for the ball on the left). In the other, the spatiotemporal path of the arm changed whereas its target object remained the same (e.g., she reached for the bear on the right). Woodward reasoned that if infants encoded the action as object-directed, they should view test trials in which the goal object changed as more novel than test trials in which the spatiotemporal path changed. Results supported this hypothesis. Both 5- and 9-month-olds dishabituated to the change in goal relative to the change in path. Thus, by 5 months (and in some cases even earlier, see Sommerville et al., 2005), infants selectively encode the goal object of an actor's reach. They do so not only for humans, but also for nonhuman agents displaying sufficient cues to animacy (Biro & Leslie, 2007; Hofer et al., 2005; Luo, in press; Luo & Baillargeon, 2005; Shimizu & Johnson, 2004). Importantly, infants do not respond selectively to changes in goals when the reaching entity is not identified as an agent (Woodward, 1998; Hofer et al., 2005) or when the action is ambiguous (e.g., contacting the goal object with the back of one's hand; Woodward, 1999).

Extensions of this work have also found that by 12 months, infants appreciate the goal-directedness of more subtle goal-directed human behaviors such as pointing (Woodward & Guajardo, 2002), gazing (Woodward, 2003; Luo, 2010) and emoting (Phillips, Wellman, & Spelke, 2002), as well as more complex successful means-ends actions and higher-order instrumental goals (Sommerville & Woodward, 2005; Sommerville, Hildebrand, & Crane, 2008; Woodward & Sommerville, 2000).

Gergely, Csibra and colleagues (Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Gergely, Nadasdy, Csibra, & Biro, 1995) also examined infants' understanding of successful goal-directed actions and, more specifically, whether infants can interpret and predict others' goal-directed actions by applying the rationality principle. Using the violation-of-expectations paradigm, 12-month-olds (Gergely et al., 1995), 9-month-olds, and 6-month-olds (Csibra et al., 1999) were shown events involving a computer-generated, two-dimensional display of abstract agents (i.e., balls) performing goal-

directed motions. Infants were habituated to an event in which a small ball moved on an arcing path over a rectangular barrier that separated it from a large ball. In this experiment, the goal-state was reaching and contacting the large ball. Following habituation, infants were shown two test events in which the rectangular barrier was removed. In the direct test event, the first ball moved directly in a straight line toward the second ball: the ball followed a new path, but the action was an efficient means to the goal in the new situation. In the indirect test event, the ball moved in the same path as in habituation even though the barrier no longer intervened. That is, the ball's movement was identical to that in habituation, but in this new situation (because the barrier was absent) the action was no longer an efficient means to the goal. Results revealed that 9- and 12-month-olds looked longer at the indirect test event suggesting that infants (1) interpret others' actions as goal-directed, (2) evaluate which of the alternative actions available within the constraints of the situation is the most efficient means to the goal, and (3) expect the agent to perform the most efficient means available. This pattern of results followed whether the balls exhibited animacy cues (non-rigid transformation, contingent reciprocal reactivity at a distance, and self-propulsion with direction change; Gergely et al., 1995) or not (Csibra et al., 1999). The same pattern of results was observed for infants as young as 6½ months when the inanimate agent was self-propelled and exhibited variability in its approach to the goal (Csibra, 2008).

Phillips and Wellman (2005) provide similar findings for 12-month-olds using displays of a human actor reaching for a goal object. Infants were habituated to an actor reaching over a barrier with an arcing motion to successfully retrieve a ball. After habituation, infants saw two test displays in which the barrier was removed. In the direct test event, the actor reached directly for the ball and successfully obtained it. In the indirect test event, the actor reached in the same arcing path as during habituation (even though the barrier was absent) and successfully obtained the ball. Results showed that infants looked longer at the indirect than the direct test event providing further evidence that young infants encode successful human actions in terms of their goals (see also Sodian, Schoeppner, & Metz, 2004).

Thus, evidence from a variety of studies clearly suggests that during the first year of life, infants encode successful goal-directed actions not only as perceptual movements

through space, but also as actions that are directed toward goals. Moreover, infants are sensitive to the environmental contexts in which goal-directed actions take place (for more evidence, see Carpenter, Call, & Tomasello, 2005; Gergely, Bekkering, & Kiraly, 2002; Schwier, van Maanen, Carpenter, & Tomasello, 2006; Zmyj, Daum, & Aschersleben, 2009; for similar results with nonhuman primates, see Buttelmann, Carpenter, Call, & Tomasello, 2007; Rochat, Serra, Fadiga, & Gallese, 2008; Uller & Nichols, 2000; Uller, 2004; Wood, Glynn, Phillips, & Hauser, 2007).

Nevertheless, that infants understand successful goal-directed actions and their environmental contexts does not necessarily imply that they appreciate the *intentions* underlying those actions. Because the goal of a successful goal-directed action is instantiated in its physical outcome (e.g., grasping the bear, retrieving the ball), infants may identify the goal that the actor is moving toward on the basis of the external result of the action rather than on the basis of the intention of the actor. A critical test of whether infants possess an intentional understanding of action is one that involves situations where intentions and actions are dissonant, as in reasoning about incomplete or failed goal-directed actions—in which the action’s intention is not evident in the observed outcome of the event. In the next section, I turn to a review of the existing literature on infants’ understanding of failed or incomplete actions.

### **Experimental Evidence from Reasoning about Incomplete or Failed Actions**

The firmest demonstrations of infants’ understanding of failed intentional action come from imitation tasks that separate intentions from results. For example, Meltzoff (1995) found that after witnessing an adult try but fail to fulfill several novel, object-directed goals (e.g., trying unsuccessfully to hang a ring on a hook), 18-month-olds read through the actor’s bodily movements to the underlying intention of the action. That is, although infants never saw the actions successfully modeled, when given a chance to act on the objects themselves they “imitated” the successful goal-directed actions much more than they did the failed (actually witnessed) actions. In fact, infants were as likely to perform the target action after seeing the adult unsuccessfully attempt it as they were after seeing the full demonstration. Extensions of this study have shown that 15-month-olds (Johnson, Booth, & O’Hearn, 2001) but not 12-month-olds (Bellagamba & Tomasello, 1999) or 9-month-olds (Meltzoff, 1999) also display this pattern (see also

Carpenter, Akhtar, & Tomasello, 1998; Olineck & Poulin-Dubois, 2005; for similar results showing that chimpanzees can “imitate” failed actions, see Call, Carpenter, & Tomasello, 2005; Myowa-Yamakoshi & Matsuzawa, 2000).

On the basis of these studies, we can conclude that by around 15 months of age infants understand that failed actions are guided by underlying intentions. However, the question then arises: Can younger infants demonstrate the same understanding? This is an intriguing question given the behavioral and habituation data described earlier suggesting that infants possess at least some understanding of goal-directed behavior as early as the second half of the first year of life.

Behne, Carpenter, Call, and Tomasello (2005) used an interactive methodology to investigate the question of whether younger infants understand successful versus unsuccessful events. They asked whether infants would respond systematically differently (and appropriately) when an experimenter tried but accidentally failed to give them a toy (e.g., she accidentally dropped it) versus when she willfully failed to do so (e.g., she teased the infants with it or played with it herself). Results showed that 9-month-olds (but not 6-month-olds) responded with more impatience (e.g., reaching, looking away, banging) when the adult was unwilling to give them the toy than when she was unable to do so. Behne and colleagues interpret these results as evidence that beginning at around 9 months of age, infants perceive other people’s surface bodily movements as distinct from the intentions that motivate them (see Call, Hare, Carpenter, & Tomasello, 2004, for similar results with chimpanzees; Phillips, Barnes, Mahajan, Yamaguchi, & Santos, 2009, for similar results with capuchins).

Although these data do show that infants in the first year are not oblivious to and do not react identically to all sorts of incomplete acts, the results of Behne et al. do not directly test infants’ understanding that the experimenters’ intentions are distinct from her actions. Infants’ differential responses likely stemmed from superficial differences between the events such as the experimenter’s facial expressions and behaviors (e.g., smiling, frowning, and signs of frustration or effort). Moreover, infants may have recognized and become impatient when they were being teased without having any understanding of the goal underlying the accidental failures. Therefore, I argue that,

although these results are suggestive and intriguing, they do not convincingly tell us whether infants understand intentions.

Related data on infants' understanding of incomplete goal-directed actions come from the visual habituation studies of Csibra et al. (2003), Southgate & Csibra (2010), and Wagner and Carey (2005). In these studies, one-year-olds were able to make productive inferences about unseen aspects of an abstract agent's goal-directed action. For example, in Csibra et al. (2003; Experiment 1a), infants were habituated to a large ball chasing a small ball. The small ball passed through a small gap in a barrier and the large ball, unable to fit through the gap, moved around the barrier in pursuit. Infants were not shown what happened after the ball crossed to the other side of the barrier. At test, infants saw two new events in which the other side of the barrier was revealed. In one event, the large ball caught up with the small ball and then stopped (the catching outcome). In the other event, the large ball moved past the small ball and off the screen (the passing outcome). Infants looked longer at the passing outcome, suggesting that they represented the catching outcome as more natural or expected. This finding is an important extension of the work on infants' understanding of successful goal-directed actions as it demonstrates infants' ability to attribute a non-visible goal from an observed incomplete action. However, it does not speak to the question of whether infants can reason about the goal of a failed action—in which there is a *mismatch* between the action's overt physical outcome and the intention that motivates it.

In sum, although there is compelling evidence that by 15 months of age infants understand intention, studies exploring infants' understanding of failed actions during the first year of life are less convincing<sup>1</sup>.

### **Summary and Open Questions**

Taken together, the following picture is emerging from research on infants' understanding of goals and intentions: First, as demonstrated in their spontaneous interactions with others, infants are skilled social actors; yet, from these interactions

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<sup>1</sup> Independently, several research labs began exploring younger infants' reactions to failed actions at the same time that I was conducting Study 1 (Daum, Prinz, & Aschersleben, 2008; Hamlin, Hallinan, & Woodward, 2009; Hamlin, Newman, & Wynn, 2009; Legerstee & Markova, 2008). Since Study 1 did not follow and was not informed by these studies, I do not discuss them here. Instead, I review this research in the General Discussion of Study 1.

alone it is unclear whether infants' social behaviors reflect an understanding of intention. Second, during the first year of life, infants demonstrate a firm understanding of successful goal-directed actions and their environmental contexts and, thus, an understanding that human actions are rationally and efficiently directed toward concrete goals; yet, it is unclear whether this understanding of goals and goal-directedness reflects a broader, more sophisticated understanding of intentions. Third, during the second year of life, infants demonstrate a clear understanding of failed actions and, hence, an understanding of intentions and intentionality; yet, it is unclear whether this understanding is present earlier.

Thus, on the basis of prior research, three critical questions remain. First, when do infants begin to perceive failed actions as guided by intentions that are not manifested in action? Does this understanding emerge during the first year of life, as suggested by research on infants' spontaneous social behaviors (e.g., Carpenter et al., 1998; Tomasello, 1995) and reasoning about successful actions (e.g., Gergely et al., 1995; Phillips & Wellman, 2005; Woodward, 1998)? Or does it emerge later, as suggested by existing imitation studies (e.g., Meltzoff, 1995)?

Second, what is the relationship across development between reasoning about successful actions and reasoning about failed actions? Do understandings of successful actions and failed actions emerge simultaneously, as argued by theorists who attribute to infants a deep, innate understanding of intention that is automatically elicited when seeing animate movements (e.g., Baron-Cohen, 1995; Premack, 1990)? On these accounts, intention understanding would be indistinguishable from understanding goal-directedness, and an understanding of failed intentional actions would co-occur in development with an understanding of successful intentional actions. Or does an understanding of failed actions develop later than an understanding of successful actions, as argued by developmental accounts whereby a simplified understanding of goal-directedness precedes a later intentional understanding of human behavior (Phillips & Wellman, 2005; Woodward, 1998) or a teleological understanding precedes a mentalistic one (Gergely & Csibra, 2003)? On these views, intention understanding would represent a developmental advance over a simplified action- or object-based understanding of goal-



directedness and, thus, an understanding of failed actions would appear later than an understanding of successful actions that transparently instantiate their goals.

Finally, what is the process by which infants learn about failed actions? How do infants begin to discover the hidden intentions underlying human action? And how is this milestone related to other contemporaneous developmental achievements? The focus of this dissertation is these three critical questions.

### **The Present Research**

This dissertation consists of two key studies that examine an understanding of successful and failed intentional actions in infants between the ages of 8 and 12 months. Study 1 uses a habituation design to examine 8-, 10-, and 12-month-olds' understanding of directly comparable successful- and failed-reaching actions. This study addresses two main questions: (1) Do infants in the first year of life understand both successful and failed goal-directed actions? (2) When conditions are as comparable as possible, does an understanding of successful actions that transparently fulfill their goals appear earlier than an understanding of failed actions? Studies 1a and 1b test alternative explanations for the pattern of results observed in Study 1—namely, that infants' patterns of looking were driven by perceptual properties of the test stimuli rather than an understanding of intention.

Study 2 moves beyond the results of Study 1 to explore *how* infants learn about intentional actions. In this study, I use eye-tracking methodology to examine infants' on-line processing and learning about both successful- and failed-reaching actions. Specifically, through eye-tracking methodology, Study 2 asks the following questions: Can infants predict the outcome of ongoing successful- and failed-intentional actions? What do infants attend to when viewing intentional actions? How do infants' looking patterns vary depending on the outcome of the action being observed (i.e., whether the action is successful or unsuccessful)? How do infants' looking patterns change over the course of a testing session? Finally, are there age-related differences in both the elements infants initially attend to and the ways in which infants' looking patterns change over the course of a testing session? To investigate how the development of an understanding of intention is related to other contemporaneous developmental milestones, Study 2 also includes a parent-report measure of infant motor behaviors (e.g., crawling, walking,

means-end behavior production) and social behaviors (e.g., pointing, imitating, gaze following, joint attention) presumed to be related to the development of intention understanding (e.g., Bretherton, 1991; Campos et al., 2000; Tomasello, 1995).

Overall, by investigating the development of reasoning about both failed and successful actions, this dissertation sheds light on the emergence of an intentional understanding of human behavior in infancy.

## CHAPTER II

### *STUDIES 1, 1a, and 1b*

#### Study 1<sup>2</sup>

Study 1 addressed two main questions: (1) Do infants in the first year of life understand both successful and failed goal-directed actions? (2) When conditions are as comparable as possible, does an understanding of successful actions that transparently fulfill their goals appear earlier than an understanding of failed actions?

To explore these questions, I devised a visual habituation paradigm. Looking-time paradigms are often better-suited to the motor capacities of younger infants since infants can evidence informative patterns of attention well before they can engage in complex motor actions of the sort needed to be successful in the imitation procedure (e.g., Meltzoff, 1995). Moreover, this paradigm allowed a direct comparison of infants' understanding of successful and failed intentional actions.

The habituation and test events are shown in Figure 1. The *successful action* condition was identical to the experimental condition of Phillips and Wellman (2005): an actor reaches over a barrier with an arcing arm motion and successfully retrieves a ball. In the *failed action* condition, infants saw a parallel display in which the actor reaches over the barrier with an arcing arm motion, however, crucially, the actor's reach is unsuccessful: the reach falls short of grasping the ball. Infants were then shown two test events and, importantly, these test events were identical across condition. In the *direct* test event, the actor reaches directly for the ball and, with no barrier to interfere, successfully obtains it. The arm traces a new path, but the action is consistent with the previous goal of directly reaching the ball. In the *indirect* test event, the actor reaches in an arcing path (although the barrier is gone) and successfully obtains the ball. The arm

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<sup>2</sup> Note that portions of Study 1 were taken from Brandone & Wellman (2009).

movement is identical to that in habituation and the action is successful, but it is no longer consistent with attempting to directly reach the goal-object.

I predicted that if infants can infer the goal of a *failed*-reaching action, they should look longer at the indirect than at the direct test event, just as they do when habituated to successful reaches. Furthermore, if an understanding of successful goal-directed actions precedes an understanding of failed actions, I should find an age at which infants in the successful-reaching condition look longer at the indirect event and infants in the failed-reaching condition do not.

### *Method*

#### **Participants**

Participants included 132 8-, 10-, and 12-month-olds (66 males, 68 females; 8-month-olds:  $n = 46$ ,  $M = 7.91$ ,  $SD = 0.28$ ; 10-month-olds:  $n = 44$ ,  $M = 9.73$ ,  $SD = 0.48$ ; 12-month-olds:  $n = 44$ ,  $M = 11.80$ ,  $SD = 0.40$ ). Thirty-seven additional infants were excluded for fussiness ( $n = 18$ ), observer error ( $n = 14$ ), interference ( $n = 4$ ), and computer problems ( $n = 1$ ). Infants were assigned to the *successful-reaching* (8-month-olds:  $n = 23$ ,  $M = 7.79$ ; 10-month-olds:  $n = 24$ ,  $M = 9.55$ ; 12-month-olds:  $n = 24$ ,  $M = 11.70$ ) or *failed-reaching* conditions (8-month-olds:  $n = 23$ ,  $M = 8.03$ ; 10-month-olds:  $n = 20$ ,  $M = 9.94$ ; 12-month-olds:  $n = 20$ ,  $M = 11.91$ ). Participants were predominantly European American and from middle-income homes.

#### **Procedure**

Infants sat on their parent's lap in front of a computer monitor. Video events<sup>3</sup> were presented in an infant-controlled habituation design (Cohen et al., 2004). A trial ended when the infant looked away for 2 continuous seconds or after 60 seconds, whichever came first.

Infants saw a minimum of 4 and maximum of 10 habituation trials, followed by 6 test trials. Test trials began once the average looking-time across three consecutive trials dropped below 50% of that during the first three trials. Looking times to each trial were

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<sup>3</sup> Video events were chosen over live presentations to ensure consistency across the successful and failed conditions. Prior research by Phillips and Wellman (2005) demonstrated that 12-month-olds treated videos of an actor reaching identically to equivalent live displays.

coded on-line. Test trials for 33% of participants were re-coded by a second coder. Observers' judgments agreed within 1 second or less on 93.7% of trials.

### ***Habituation events***

Infants saw one of two events. In the *successful-reaching* condition, a man is seated (in profile) at a table in front of a wall-like barrier and a brightly colored ball. The actor reaches over the barrier (with an arcing motion), grasps the ball, brings it back to his torso (tracing the same arcing motion), and the video freezes (Figure 1a).

The *failed-reaching* condition habituation event is identical except that the reach is *unsuccessful*. The actor reaches over the barrier with the same arcing motion as in the successful-reaching condition; however, his reach falls short of the ball. At the furthest extension of his reach he neither grasps nor occludes the ball with his hand. He brings his empty hand back to his torso and the video freezes.

### ***Test events***

Following habituation, infants in both conditions were shown two test events (identical to those in Phillips & Wellman, 2005). In both events, the barrier is absent and the actor successfully grasps the ball. In the *direct-reach event*, the man reaches directly (in a straight line) for and grasps the ball. He brings it back to his torso (following the same straight path) and the video freezes. In this event, the arm traces a path that is perceptually different from the arcing path in habituation; however, the action is consistent with the prior goal of directly reaching for the ball (Figure 1b). In the *indirect-reach event*, the actor reaches for the ball in the same arcing path as in habituation even though the barrier is absent. He grasps the ball, brings it back to his torso, and the video freezes. Here the path is perceptually identical to that in habituation; however, the action is inconsistent with the prior goal of directly reaching for the ball. Test events were shown three times each in an alternating sequence and counterbalanced order.

## ***Results and Discussion***

### **Habituation**

On average, infants watched 9.06 trials ( $SD = 1.56$ ) and spent 96.77 seconds ( $SD = 42.84$ ) viewing the habituation events. This did not differ across condition or age group. Many infants did not meet the habituation criterion (successful-reaching

condition: 63.4% of infants; failed-reaching condition: 65.1% of infants), but what is critical is that infants received sufficient exposure to and began to lose interest in the habituation events. Average looking times to the first and last habituation events were entered into an analysis of variance (ANOVA) with trial (first, last) as the within-subject factor and age group (8-, 10-, 12-months) and condition (successful-reaching, failed-reaching) as the between-subjects factors. There was a main effect of trial,  $F(1, 125) = 48.14, p < .001, p_{rep} = .99, \eta_p^2 = .28$ , and an interaction of trial by condition,  $F(1, 125) = 6.14, p = .015, p_{rep} = .94, \eta_p^2 = .047$ . Looking-times declined significantly across the habituation phase in both conditions, although the decrement of attention was greater in the failed- (first trial:  $M = 14.76$ ; last trial:  $M = 7.56$ ) than in the successful-reaching condition (first trial:  $M = 11.63$ ; last trial:  $M = 8.22$ ). This looking-time decline did not differ as a function of age group.

## Test

The central hypotheses concerned (a) whether infants look longer at the indirect test event in the failed- as well as the successful-reaching condition, and (b) whether at some age infants look longer at the indirect test event in the successful- but not the failed-reaching condition. I tested for these patterns using planned comparisons between the conditions at each age. I began with ANOVA to examine the overall pattern of results and, because looking-time data are consistently skewed and non-normal (in this and other research; e.g., Spelke et al., 1992), I confirmed the parametric planned comparisons with nonparametric tests.

In the ANOVA with test event (direct, indirect) as the within-subject factor and age group (8-, 10-, 12-months), condition (successful-reaching, failed-reaching), and gender (male, female) as the between-subjects factors, there were significant effects of condition, age, and test event. Critically, there was a significant main effect of test event,  $F(1, 122) = 38.09, p < .001, p_{rep} = .99, \eta_p^2 = .24$ , and a significant interaction of condition by age group  $F(2, 122) = 4.72, p = .011, p_{rep} = .95, \eta_p^2 = .072$ . Bonferroni-adjusted pairwise comparisons revealed that, overall, infants looked significantly longer at the indirect ( $M = 9.47, SD = 4.38$ ) than the direct test event ( $M = 7.62, SD = 3.41$ ). Moreover, both 10- and 12-month-olds looked longer at the test events in the failed- than in the

successful-reaching condition, whereas 8-month-olds looked equally during both conditions.

For the planned pairwise comparisons (Bonferroni-adjusted), in the *successful-reaching* condition, infants of all ages looked significantly longer at the indirect- than at the direct-reach events (see Figure 2; 8-month-olds:  $F(1, 122) = 5.30, p = .023, p_{rep} = .92, \eta_p^2 = .042$ ; 10-month-olds:  $F(1, 122) = 10.19, p = .002, p_{rep} = .98, \eta_p^2 = .077$ ; 12-month-olds:  $F(1, 122) = 11.40, p = .001, p_{rep} = .99, \eta_p^2 = .085$ ). In contrast, in the *failed-reaching* condition, only the 10- and 12-month-olds looked significantly longer at the indirect- than the direct-reach events (10-month-olds:  $F(1, 122) = 5.81, p = .017, p_{rep} = .93, \eta_p^2 = .045$ ; 12-month-olds:  $F(1, 122) = 9.37, p = .003, p_{rep} = .97, \eta_p^2 = .071$ ). Eight-month-olds looked equally long at both test events,  $F(1, 122) = 0.62, p = .43, p_{rep} = .55, \eta_p^2 = .005$ .

Because infant looking times are often not normally distributed, I confirmed these results with non-parametric, Wilcoxon Signed Ranks tests. In the *successful-reaching* condition, 8- ( $Z = 2.07, p = .039, p_{rep} = .89$ ), 10- ( $Z = 3.21, p = .001, p_{rep} = .99$ ), and 12-month-olds ( $Z = 3.51, p < .001, p_{rep} = .99$ ) all looked significantly longer at the indirect than the direct events. In the *failed-reaching* condition, 10- ( $Z = 1.98, p = .048, p_{rep} = .88$ ) and 12-month-olds ( $Z = 2.45, p = .014, p_{rep} = .94$ ) looked significantly longer at the indirect- than at the direct-reach events; 8-month-olds, however, did not ( $Z = 0.70, p = .48, p_{rep} = .51$ ).

## Summary

In sum, results suggest that 10- and 12-month-olds recognized the goal-directedness of both the successful- and failed-reaching actions. Eight-month-olds, on the other hand, recognized the goal-directedness of successful but not failed reaching actions.

## Studies 1a and 1b

Infants' longer looking to the indirect test event (as compared to the direct test event) in Study 1 may be interpreted as evidence of infants' understanding of goals and intentions. However, an alternative explanation for this finding is that longer looking to the indirect test event is instead driven by *perceptual properties* of the test stimuli. In

particular, longer looking to the indirect event could simply reflect a preference for looking at arcing arm movements. Note that such a preference cannot account for the 8-month-olds' pattern of responses because, although test events were identical across the successful and failed reaching conditions, 8-month-olds looked longer at the indirect than at the direct events only in the successful-reaching condition. To explore this alternative with 10- and 12-month-olds, I conducted two control studies.

Study 1a provided a basic check of the perceptual properties of the test stimuli by presenting 10- and 12-month-olds with the direct and indirect test trials from Study 1 without habituation experience. I predicted that if the results observed in Study 1 were driven by basic perceptual properties of the test stimuli, then infants should look longer at the indirect reach event even without habituation experience.

Study 1b provided an additional test of whether or not the results of Study 1 may be driven by a preference for looking at arcing arm movements. If infants' responses to the test events are an indication of their understanding of goals and intentions, then the goal object (i.e., the ball) should be a critical component of the habituation test events. In contrast, if infants' responses to the test events reflect perceptual preferences alone, then the goal object should play a negligible role in the habituation and test events. To explore these possibilities, in Study 1b, 10- and 12-month-olds were presented with habituation and test events that were identical to those in Study 1 except that there was no goal object present. I predicted that if the results observed in Study 1 were driven by perceptual preferences alone, then infants should look longer at the indirect reach event even in the absence of the goal object.

### *Method: Study 1a*

#### **Participants**

Participants included 16 infants between the ages of 10 and 12 months (8 males, 8 females;  $M = 10.31$  months,  $SD = 0.81$ ). Five additional infants were excluded for fussiness ( $n = 4$ ) and interference ( $n = 1$ ). Participants were predominantly European American and from middle-income homes.



## **Procedure**

The procedure was identical to the test procedure in Study 1. Infants were shown two video test events: the direct-reach and the indirect-reach event. Test events were shown three times each in an alternating sequence and counterbalanced order.

### ***Results and Discussion: Study 1a***

Average looking times to the test events were entered into an ANOVA with test event (direct, indirect) as the within-subject factor and gender (male, female) as the between-subjects factor. There were no significant main effects or interactions. Critically, the effect of test event was nonsignificant. Infants looked equally at the indirect ( $M = 13.66$ ,  $SD = 4.29$ ) and direct test events ( $M = 12.50$ ,  $SD = 5.01$ ; see Figure 3). This result was confirmed with non-parametric, Wilcoxon Signed Ranks tests,  $Z = -1.29$ ,  $p = .20$ . These data show that, without habituation experience, infants did not look longer at the indirect test event. Results rule out the possibility that infants' longer looking to the indirect reach in Study 1 resulted from basic perceptual properties of the test stimuli.

### ***Method: Study 1b***

The more serious possibility is that viewing extended presentations of reaching during habituation sets up expectations for the test events but expectations that have nothing to do with intentions or goal-directedness. This can be tested by habituating infants to identical arcing reaches over a barrier but where there is no goal-object—no ball. This condition serves substantive as well as methodological aims: If infants appreciate goal-directed intentions, then the presence or absence of a goal-object should crucially influence their reactions.

## **Participants**

Participants included 46 10- and 12-month-olds (22 males, 24 females; 10-month-olds:  $n = 22$ ,  $M = 9.68$ ,  $SD = 0.44$ ; 12-month-olds:  $n = 24$ ,  $M = 11.59$ ,  $SD = 0.46$ ). Twelve additional infants were excluded for fussiness ( $n = 7$ ), observer error ( $n = 4$ ), and interference ( $n = 1$ ). Participants were predominantly European American and from middle-income homes.

## **Procedure**

During habituation, the actor reached in an arcing manner over the barrier (as in Study 1) but there was no goal-object (Figure 4a). During test, the barrier was removed and infants saw direct- and indirect-test events that were identical to those in the focal conditions, but without a ball (Figure 4b).

### ***Results and Discussion: Study 1b***

#### **Habituation**

On average, infants watched 8.89 habituation trials ( $SD = 1.66$ ) and spent 84.77 seconds ( $SD = 39.88$ ) viewing the habituation events. This did not differ across age group. As in Study 1, many infants (63.0%) did not meet the habituation criterion, but what is critical is that infants received sufficient exposure to and began to lose interest in the habituation events. Average looking times to the first and last habituation events were entered into an ANOVA with trial (first, last) as the within-subject factor and age group (10-, 12-months) as the between-subjects factor. Results revealed a main effect of trial,  $F(1, 44) = 7.56, p = .009, \eta_p^2 = .15$ , such that looking-times declined significantly across the habituation phase (first trial:  $M = 10.68, SD = 6.12$ ; last trial:  $M = 7.61, SD = 4.96$ ). This looking-time decline did not differ as a function of age group.

#### **Test**

Average looking times to the test events were entered into an ANOVA with test event (direct, indirect) as the within-subject factor and age group (10-, 12-months) and gender (male, female) as the between-subjects factors. There were no significant main effects or interactions (see Figure 3). Critically, the effect of test event was nonsignificant. Infants looked equally at the indirect ( $M = 7.79, SD = 4.71$ ) and direct test events ( $M = 6.76, SD = 3.55$ ). This result was confirmed with non-parametric, Wilcoxon Signed Ranks tests,  $Z = -1.26, p = .21$ .

#### ***Summary***

Performance in these control condition rules out the possibility that infants simply prefer and thus look longer at the indirect, curvilinear reach. Moreover, data from Study 1b provide an informative contrast between reaching with and without a goal-object. When an action is not directed at a goal-object, infants view reaching in a straight line or

an arc as simply different patterns of movement—neither more interesting nor interpretable than the other. In contrast, when the action is directed at a goal-object (Study 1) and infants recognize this goal-directedness (10- and 12-month-olds in both conditions; 8-month-olds in the successful-reaching condition), infants view the manner of reaching in terms of its consistency with the actor's goal (i.e., directly reaching for the ball).

### **General Discussion: Studies 1, 1a, and 1b**

These studies examined how infants in the first year of life interpret both successful- and failed-reaching actions. Results of Study 1 showed that 8-, 10-, and 12-month-olds encoded *successful*-reaching actions in terms of their goals and not simply in terms of their surface perceptual features. Critically, results indicated that 10- and 12-month-olds (but not 8-month-olds) also encoded *failed*-reaching actions in terms of their goals. Finally, additional data from two control studies ruled out the possibility that infants' performance in Study 1 was based solely on basic perceptual properties of the test stimuli or a visual preference for curvilinear arm movements. Together, these data speak to two key questions regarding the development of intention understanding. First is the question of when in development infants first understand failed intentional actions. Second is the question of what is the relationship across development between reasoning about successful and failed actions.

#### **When Do Infants Understand Failed Intentional Actions?**

The data presented here extend prior work (e.g., Meltzoff, 1995) by revealing infants' understanding of failed actions during the first year of life. Through the use of a minimally demanding looking-time procedure and a simple, familiar, human action that infants themselves can perform (reaching), these data show that even 10-month-olds possess a nascent understanding of the goal-directedness of failed actions. These findings also fit with and extend other recent studies that have examined whether infants in the first year of life perceive failed actions as guided by intentions that are not manifested in action.

First, Legerstee and Markova (2008) simplified the behavioral reenactment paradigm of Meltzoff (1995) through the use of simple, familiar actions and a modified

coding scheme. Ten-month-olds watched as an agent modeled simple, familiar goal-directed actions on objects (e.g., putting things into or taking them out of bowls). Some actions were successful; some were unsuccessful. After each action was modeled, infants were given an opportunity to act on the objects themselves. Instead of using the stringent all-or-nothing coding scheme used by Meltzoff and others (Bellagamba & Tomasello, 1999; Meltzoff, 1995; Johnson et al., 2001), Legerstee and Markova assigned infant responses a score ranging from 1 to 5, depending on the extent to which infant responses resembled the target acts (e.g., putting a toy into or taking it out of a container). A score of 1 was given when an infant played with one object (toy, container) at a time, 2 when an infant played with both objects but did not touch the objects together, 3 when an infant played with both objects and touched them together, without reproducing the target action, 4 when an infant reproduced the action of the agent differently or clumsily, and 5 when an infant clearly imitated the target action.

With these modifications, Legerstee & Markova found that 10-month-olds responded appropriately both when a human agent modeled a successful action and when the human agent modeled an unsuccessful action. Moreover, infants received higher scores following successful and unsuccessful action demonstration than they did in a baseline phase designed to test infants' spontaneous production of the target acts. Interestingly, Legerstee and Markova also found that, although infants imitated the successful actions of both human and nonhuman agents (a person in a dog costume, a set of mechanical pincers), infants imitated the intentions of the unsuccessful actions of humans only.

Although Legerstee and Markova (2008) concluded that their findings demonstrate an awareness of the intentions underlying human action in the first year of life, it is unclear from these studies whether infants' behavioral responses truly reflect an understanding of intention. In particular, scores from the authors' modified coding scheme are difficult to interpret. Only scores of 5 and arguably 4 reflect completion of the intended target action, so it is impossible to determine whether lower scores reflect an attempt to produce the target action or not. Thus, although this microanalysis of infants' behaviors is useful for capturing approximations toward the target actions, it is less useful for determining whether infants possess an intentional understanding of behavior.

Hamlin, Hallinan, and Woodward (2009) also simplified Meltzoff's (1995) imitation paradigm for use with younger infants. Seven-month-olds viewed an actor performing one of the following actions directed at one of two objects: (a) reaching and grasping, (b) reaching but failing to grasp, (c) touching with the back of the hand, and (d) pointing. Infants were then given an opportunity to interact with the objects themselves. Hamlin and colleagues were interested in whether infants would selectively imitate the goal-relevant aspects of the observed actions. Results revealed that in both the grasping and the incomplete grasping conditions, infants touched the target object at a rate significantly greater than chance. In the ambiguous back of the hand and pointing conditions, however, infants were equally likely to touch the target and nontarget objects.

These findings suggest that infants may understand the actor's incomplete goal; however, they are open to alternative interpretations. Most critically, it is not clear that infants were in fact imitating the failed grasp. Unlike the research with older infants (where imitation was clear in infants' repetition of extended, novel, object-directed behaviors), here the actor's reaching may have simply triggered a familiar action sequence. That is, it is possible that infants' own reaching/touching behavior was not an imitation of the goal of the incomplete action but rather a continuation of the next step in a familiar behavioral sequence—reaching for and grasping an object. The current data are not subject to this alternative interpretation because, in the study presented here, infants' reaction to reaching was not measured by their own reaching but rather by their patterns of visual attention. Moreover, in both test events (direct and indirect) the actor successfully retrieved the object, so both test events portrayed a complete, familiar action sequence.

Daum, Prinz, and Aschersleben (2008) used a preferential looking paradigm to explore infants' ability to encode the goal of incomplete, goal-directed reaching actions similar to those shown in Hamlin et al. (2009). Infants watched videos of an actor's hand reaching towards one of two objects and stopping midway between the starting point and the location of the target object. Subsequently, two final states of the reaching movement were presented simultaneously: one consistent with the goal of the initial reach and one inconsistent with the goal of the initial reach. Results showed that both 6- and 9-month-olds looked longer at the inconsistent final state. As in the case of Hamlin et al. (2009),

these results may suggest an understanding of the actor's intention; however, they may also reflect a simple extrapolation of the motion path of the actor's hand without considering any kind of goal-directedness. In particular, in this study an appropriate response could be achieved simply by recognizing in which of two directions (left or right) the actor's hand was moving without any consideration of the goal object. Notably, longer looking at the inconsistent final state was found only if the scene was presented from an allocentric perspective (as though the reaching agent were seated across from the infant), not if it was presented from an egocentric perspective (as though the infant were the reaching agent). Daum and colleagues speculate that this may have stemmed from differences in infants' familiarity with the two perspectives (e.g., more experience interpreting the action of those sitting opposite them). Nevertheless, the fact that infants did not perform consistently in the allocentric and egocentric conditions complicates the authors' interpretation that infants possess a true understanding of intention.

Finally, Hamlin, Newman, and Wynn (2009) tested whether 8-month-olds could infer an actor's unfulfilled goal, despite the fact that some physical information present in the displays was inconsistent with the attempted goal. Infants saw a hand holding a ring repeatedly approach the top of a plastic cone in a failed attempt to place the ring on the cone. The hand and ring then bounced away from the top of the cone toward the floor. Thus, some information presented was relevant to the goal (i.e., the hand motion toward the goal, the afforded relationship between the ring and the cone, and the repeated attempt), but some of it was irrelevant to the goal (i.e., the movement away from the goal). Infants were presented with two test events: one that was consistent with the trajectory information but inconsistent with the goal, and one that was consistent with the goal. Eight-month-olds looked longer to the trajectory consistent/goal inconsistent event, suggesting they were able to infer the goal despite the physical ambiguity. Infants who had not been habituated to the failed attempt (saw only the test events) or who saw a matched inanimate control did not show this pattern others. This study provides the most convincing of the additional evidence of failed action understanding in infancy, and it offers intriguing results on infants' responses to a failed action performed by an inanimate agent. Nevertheless, without a successful action comparison condition, it remains difficult to interpret.

In sum, the current results provide the most comprehensive and controlled demonstration of early infant understanding of the intentions behind failed actions. None of these other studies alone provides as clear an answer to the question of whether infants understand intention. However, together with the results of the study presented here, these recent data provide a compelling pattern of evidence that infants in the first year of life perceive failed actions as guided by intentions that are not manifested in action.

### **What is the Relationship across Development between Reasoning about Successful and Failed Actions?**

The data presented here not only demonstrate early understanding of the goals behind failed actions, but also—uniquely— directly compare infants’ understanding of successful and failed goal-directed actions. With this comparison, the current studies demonstrate an age at which infants infer the goal of a successful-reaching action, but fail to do so for a directly comparable failed-reaching action. This conclusion depends, in part, on the youngest infants’ failure to produce a significant difference in the failed-reaching condition, and null findings are always subject to alternative interpretations. For example, the videotaped nature of the events may have hindered the youngest infants’ performance. This seems unlikely, however, because the failed- and successful-reaching presentations were both videotaped and the youngest infants succeeded in the successful-reaching condition. Alternatively, the youngest infants may have had special difficulty completing the means-end analysis required to understand the process of reaching around a barrier. This also seems unlikely because 8-month-olds successfully completed the same means-end analysis in the successful-reaching condition.

Thus, the alternative I favor is that this pattern of results (succeeding in the successful- prior to the failed-reaching condition) illustrates a developmental trajectory whereby understanding successful goal-directed actions precedes understanding failed goal-directed actions. That is, infants are first able to infer an actor’s goal while or after observing the actor visibly instantiate it in action (e.g., successfully grasping and retrieving the goal-object). At this early age, however, infants need outcome information to determine the goal of an action. In contrast, somewhat older infants are able to infer the goal of an action even when that goal is unrealized and no visible achievement of the goal-object is available to instantiate the goal. As others have argued (e.g., Meltzoff,

1995), because an appreciation of behavior as goal-directed in the absence of overt goal-fulfillment seems impossible without at least a rudimentary understanding of goals as distinct from the actions that achieve them, this ability to infer the goal of a failed action marks an important step toward understanding actions as *intentional*. That 10- and 12-month-olds in this experiment are able to construe a familiar, transparently goal-directed human action, such as reaching, as guided by intentions certainly does not imply that at this age infants apply a sophisticated, intentional or mentalistic framework broadly to all human actions. Nevertheless, these data illustrate the early emergence of an intentional framework in at least one key instance of human action. Moreover—consistent with the theoretical proposals of Gergely and Csibra (2003), Wellman and Phillips (2001), and Woodward (1998)—these data show that this early intentional understanding of action appears later than, and potentially builds upon, a prior, action- and object-based understanding.

## **Conclusion**

Study 1 set out to address two fundamental questions regarding the development of intention understanding in infancy. First, when do infants perceive failed actions as guided by intentions that are not manifested in action? Second, what is the relationship across development between reasoning about successful and failed actions—actions that do and do not directly manifest their underlying intentions? The data presented here demonstrate an impressive, early intentional understanding that first emerges in 10- and 12-month-olds' appreciation of failed human actions (specifically failed human reaches). Furthermore, these data provide clear support for the hypothesis that an intentional understanding of human action represents a developmental advance over a simplified action- or object-based understanding of human behavior.



## CHAPTER III

### *STUDY 2*

Data from Study 1 and control Studies 1a and 1b suggest that an understanding of failed actions is present in the first year of life and that the period between 8 and 10 months is an important window for the development of that understanding. A key open question that arises from these data is *how* this development occurs. What are the mechanisms by which infants learn about failed actions? And how do infants begin to discover the hidden intentions underlying human action? In Study 2, I aimed to shed light on these questions by further examining 8- and 10-month-olds' processing of successful and failed intentional actions. The goals of Study 2 were twofold.

#### **Goal 1: Characterizing Infants' Processing of Intentional Actions in Real Time**

The central goal of Study 2 was to better characterize 8- and 10-month-olds' understanding of successful and failed intentional actions. Based on Study 1, we know that there are developmental differences in how infants process successful- and failed-reaching actions. In Study 1, 10- and 12-month-olds reasoned appropriately about both successful- and failed-reaching actions. Eight-month-olds, on the other hand, did so for successful actions only; they did not demonstrate recognition of the goal-directedness of failed actions. As discussed in Study 1, these results are consistent with the view that an understanding of intentions as distinct from actions develops sometime after the age of 8 months and is present in 10- and 12- month-olds. However, further validation and clarification of this account is required. Thus, the first goal of Study 2 was to better characterize similarities and differences in infants' processing of both successful and failed intentional actions in order to gain insight into both *what* changes between 8- and 10-months and, ultimately, *how* that change occurs.

To accomplish this goal, Study 2 moved beyond the global measures of looking that habituation provides, to the fine-grained, real-time measures of looking offered by eye-tracking methodology. Eye tracking enables a number of potential advances over

habituation (see Aslin, 2007; Aslin & McMurray, 2004)—in particular, I argue, with respect to better understanding the nature of the development of intention understanding in infancy. First, eye tracking can tell us what specifically infants are attending to when viewing intentional actions (e.g., the actor? the trajectory of the action? the goal?) and how they shift their attention among these targets as the actions unfold over time. Second, through the use of eye tracking, we can consider how infants' detailed looking patterns vary depending on the outcome of the action being observed (i.e., whether the action is successful or unsuccessful). Third, eye tracking enables us to examine how infants' looking patterns change both over the course of a testing session and over developmental time.

Most importantly, eye tracking further enables us to examine infants' *anticipatory looking patterns*. Previous eye tracking research examining patterns of eye movement and goal-directed action has shown that when performing goal-directed actions, adults produce predictive looks to the goal of the action. That is, they look at the goal of the action before the action is completed. Such predictions occur for events ranging from simple manual actions, such as reaching for and moving objects between different locations (Johansson, Westling, Backstrom, & Flanagan, 2001), to complex tasks such as preparing a cup of tea (Lee, Young, Reddish, Lough, & Clayton, 1983). Beginning in infancy, predictive gaze shifts are also produced when humans observe others engaging in successful, functional, goal-directed actions (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Flanagan & Johansson, 2003; Gredebäck & Melinder, 2010; Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & von Hofsten, 2009).

To illustrate, consider the example of Falck-Ytter et al. (2006). In this study, 6-month-olds, 12-month-olds, and adults were presented with videos in which an actor either placed toys inside a bucket or sat passively as the toys moved on their own to the bucket. The variable of interest was when participants first looked to the goal location (i.e., the bucket) and whether they did so before or after the toy arrived there. Falck-Ytter and colleagues found that the gaze of both adults and 12-month-olds arrived at the bucket before the hand and toy did. That is, participants predicted the outcome of the action before the action was completed. However, adults' and 12-month-olds' gaze was not anticipatory when the toys moved to the bucket on their own. In this condition,

participants tracked the self-moving toy (reactively) to its goal. Falck-Ytter and colleagues also found that the youngest infants, 6-month-olds, failed to predict the goal even when a human actor moved the toys. That is, 6-month-olds shifted their gaze to the goal location only *after* the toy arrived there in both conditions. This overall pattern of results supports two important conclusions. First, when observing successful goal-directed actions, 12-month-olds focus on goals in much the same way as adults do. And, second, there are age-related differences in how infants process successful goal-directed actions in real time.

It remains an open question, however, how infants and undergraduates process a *failed* goal-directed action in real time. In particular, do infants and undergraduates predict the goal of another's action, even when the action fails and the goal is never achieved? Moreover, are there age-related differences in how infants process and anticipate failed goal-directed actions? Finally, how does the ability to predict the goal of a failed goal-directed action compare to the ability to do so for a successful goal-directed action? Recall that the distinction between successful and failed actions is particularly important because, unlike in successful actions (which transparently instantiate their goals), in failed actions the outcome and observed pattern of motion is inconsistent with the intention that motivates it. Predicting the goal of a failed action therefore requires at least a rudimentary understanding of intentions as distinct from actions. Thus, in the current study, I examined the ability of 8-month-olds, 10-month-olds, and undergraduates to process and predict the outcome of both successful- and failed goal-directed actions using eye-tracking methodology.

## **Goal 2: Examining the Relation between Intention Understanding and Social and Motor Development in Infancy**

An important, but secondary goal of Study 2 was to explore how variability in understanding intention as revealed in the eye-tracking task may be related to variability in the behaviors and abilities of infants outside of the laboratory. The development of an understanding of intention has been hypothesized to be linked to the development of various other important skills and behaviors of infants in their daily lives. In particular, intention understanding has been proposed to be intimately related to changes in infants' production of social behaviors that fall under the category of *joint attention* (e.g.,

Bretherton, 1991; Carpenter et al., 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; see Mundy, Block, Delgado, Pomares, Van Hecke, & Parlade, 2007). The assumption that infants' joint attention abilities are importantly linked with their understanding of others' actions provides the foundation for many theories of social-cognitive development. For example, Tomasello (1999) proposed that joint attentional behaviors in which infants follow, direct, or share adult attention are all behavioral manifestations of an underlying understanding of people as intentional agents. Moreover, Moore and colleagues (Barresi & Moore, 1996; Corkum & Moore, 1995, 1998; Moore & Corkum, 1994) have proposed that joint attentional interaction plays a formative role in the development of intention understanding by providing the kinds of experiences necessary for infants to discover others' intentionality. Nevertheless, scant research has empirically tested the relation between infants' understanding of intentional actions and measures of joint attention behaviors (for a notable exception, see Brune & Woodward, 2007).

In addition, there is some reason to think that intention understanding is linked with developing motor abilities. For example, the ability to produce means-end behaviors—behaviors that involve the deliberate and planful execution of a sequence of steps to achieve a goal in situations where an obstacle prevents achieving that goal (e.g., removing a cover to search for a hidden object)—is an important developmental achievement that has been argued to serve as an indicator of infants' own intentionality and their ability to distinguish between means and goals (Piaget, 1953; Willatts, 1999), two crucial components of intention understanding. Moreover, Sommerville and Woodward (2005) have found that the ability to produce specific means-end action sequences (e.g., pulling a cloth to get a toy on its far edge) is also related to infants' understanding of those behaviors in others (see also Gredebäck & Kuchkhova, 2010). Finally, the onset of self-locomotion (i.e., crawling) has also been shown to coincide with the onset of a number of cognitive and emotional skills in infancy (Bai & Bertenthal, 1992; Campos et al., 2000; Campos, Bertenthal, & Kermoian, 1992; Herbert, Gross, &

Hayne, 2007; Higgins, Campos, & Kermoian, 1996; Kermoian & Campos, 1988; Cicchino & Rakison, 2008) that may be related to intention understanding.

Although there is some preliminary evidence to suggest that infants' emerging intention understanding is related to their developing social and motor abilities, few studies have directly tested these associations. In particular, it remains an open question whether 8- and 10-month-olds' ability to predict the goal of an ongoing intentional action is related to their developing joint attention, means-end, and self-locomotion abilities. By exploring which behaviors (if any) during this transitional period of development are related to intention understanding, the current study aimed to provide insight into potential mechanisms by which an understanding of intention develops.

### **The Current Study**

To shed light on how an understanding of intention develops in the second half of the first year, the current study examined how 8- and 10-month-olds interpret and make predictions about successful- and failed-intentional actions and, additionally, how these abilities are related to other emerging social and motor abilities.

The ability to interpret and predict the goal of successful versus failed intentional actions was examined using eye-tracking methodology. The directly comparable successful- and failed-reaching video events from Study 1 were used. Importantly, by using events that were identical to those in Study 1, the current study provided converging data from a distinct experimental paradigm (i.e., eye-tracking). As in Falck-Ytter et al. (2006) a sample of undergraduates was tested to provide a comparison with infant performance.

During the familiarization phase, participants were shown 10 trials of a man reaching in an arcing motion over a barrier for a ball and either successfully or unsuccessfully retrieving it (identical to Study 1; see Figure 1a). Then all participants were shown two test events in which the man reaches for the ball in a new context where the barrier no longer stands in the way of the ball. In these events, the actor either directly (in a straight line) or indirectly (in an arcing motion) reaches for and successfully obtains the ball (identical to Study 1; see Figure 1b).

Eye-tracking gaze data were collected and analyzed in the following ways. First, anticipatory looking patterns were examined by analyzing participants' latency to look at

the ball in both the familiarization and test events. The question of interest was whether 8-month-olds, 10-month-olds, and undergraduates can predict the goal of both successful- and failed-reaching actions. If infants and undergraduates can infer the intention of the reaching actions, they should produce anticipatory eye movements to the ball—looks to the ball that occur before the hand reaches it. I predicted that, consistent with Study 1 and other eye-tracking research (e.g., Falck-Ytter et al., 2006), participants of all ages would produce predictive eye movements to the ball while observing the successful-reaching event. In contrast, only 10-month-olds and undergraduates were predicted to do so during the failed-reaching event. I also predicted that the same pattern of results would be observed in the new context of the test events: anticipatory eye movements from 8-month-olds, 10-month-olds, and undergraduates following familiarization with a successful-reaching action, and anticipatory eye movements from 10-month-olds and undergraduates only following familiarization with a failed-reaching action. This overall pattern of results would confirm and extend the findings of Study 1—that as early as 8 months, infants encode successful actions in terms of their goals, but only later (around 10 months) do they apply this intentional interpretation to failed reaching actions.

Patterns of anticipatory looking over time (i.e., across trials) were also examined to shed light on the learning process taking place within the testing session. In particular, learning curves were compared by age group and condition. One possible pattern of results is that, after the first trial, all participants in the successful reaching condition will immediately interpret the action as directed toward the ball and hence produce anticipatory looks to the ball. This learning curve may also vary by age such that older infants and adults learn faster than do younger infants—even in the successful reaching condition. Another possible pattern of results is that the learning curve for 10-month-olds and adults will be identical across the successful and failed reaching conditions—demonstrating a similar understanding of intention that is triggered equally whether or not the actor successfully retrieves the goal. In contrast, 8-month-olds may show very different learning curves across the two conditions: quick recognition that the action is directed toward the ball and hence a steep learning curve in the successful reaching condition, and late or no recognition that the action is directed toward the ball and hence a relatively flat learning curve in the failed reaching condition.

Second, the duration of looking to each of the key components of the events (the actor's face, the trajectory of the reaching action, and the goal-object) was compared across age groups and successful- versus failed-reaching action. The goal of this analysis was to explore what participants attend to when viewing intentional actions (e.g., the actor? the trajectory of the action? the goal?) and how they coordinate and shift their attention to the key action components over time. On the assumption that visual processing reflects cognitive processing, informative differences in how older versus younger participants visually process these events could reveal key insights into how participants of different ages are interpreting intentional actions. In particular, based on data from Study 1 suggesting that 8-month-olds interpret intentional actions differently than do older infants, I predicted that 8-month-olds would show a qualitatively different pattern of visual processing than 10-month-olds and undergraduates. One possibility is that 8-month-olds will show heightened attention to salient visual cues, such as the hand's moving trajectory or the actor's face, that impede attention to other important elements of the event, such as the goal object.

Finally, infants' performance on the eye-tracking task (i.e., the speed with which they shifted their attention to the goal of the reaching actions) was examined in relation to their emerging social and motor skills. To assess these abilities, parents were asked to fill out an 18-item questionnaire including questions about joint attention behaviors, self-locomotive skills, and means-end action abilities. Twelve joint attention items covering a wide variety of joint attention skills, including abilities that involve infants' response to others' attention (e.g., following gaze) and their attempts to direct that attention of others (e.g., pointing; see Carpenter et al., 1998; Mundy et al., 2007) were included. In addition, four items assessed self-locomotion abilities (e.g., crawling, walking) and two items assessed means-end action abilities. The question of interest here was whether infants' developing social and motor abilities were indeed related to their performance on the eye-tracking task. I predicted that variability in scores on the parent-report questionnaire would be related to variability in performance on the eye-tracking task. In particular, controlling for differences as a result of age, participants with more advanced joint attention, self-locomotion, and means-end action scores were predicted to show faster anticipatory looks to the ball during the reaching events. Moreover, I predicted that these

associations would be stronger for participants in the failed-reaching condition since failed reaching more directly tests an understanding of intention. Note that these analyses are necessarily exploratory because the data rest exclusively on parental report and only concurrent correlations can be examined; nonetheless, results may prove especially informative and provide directions for more systematic future examinations.

## **Method**

### **Participants**

Participants included 56 8- and 10-month-olds (30 males, 26 females; 8-month-olds:  $n = 28$ ,  $M = 8.41$ ,  $SD = 0.31$ ; 10-month-olds:  $n = 28$ ,  $M = 10.33$ ,  $SD = 0.24$ ) as well as 25 undergraduates (13 males, 14 females). Participants were randomly assigned to either the successful- (8-month-olds:  $n = 15$ ,  $M = 8.41$ ,  $SD = 0.34$ ; 10-month-olds:  $n = 14$ ,  $M = 10.31$ ,  $SD = 0.29$ ; undergraduates:  $n = 13$ ) or the failed-reaching condition (8-month-olds:  $n = 13$ ,  $M = 8.40$ ,  $SD = 0.29$ ; 10-month-olds:  $n = 14$ ,  $M = 10.35$ ,  $SD = 0.22$ ; undergraduates:  $n = 12$ ). Seven additional infants and 5 additional undergraduates were excluded due to fussiness (8-month-olds:  $n = 1$ ), poor tracking signal (undergraduates:  $n = 2$ ), failure to calibrate (8-month-olds:  $n = 2$ ; 10-month-olds:  $n = 1$ ), or failure to meet inclusion criteria (described below; 8-month-olds:  $n = 2$ ; 10-month-olds:  $n = 1$ ; undergraduates:  $n = 3$ ). Infants were recruited by mail and follow-up telephone calls, and were given a small gift for their participation. Undergraduates were recruited from the Introduction to Psychology subject pool at a large public university and participated for course credit.

### **Apparatus**

Eye-gaze data were collected using a 17-inch Tobii 1750 eye-tracking monitor (Tobii Technology, Stockholm, Sweden) for infants and a 24-inch Tobii T60 XL eye-tracking monitor (Tobii Technology, Stockholm, Sweden) for undergraduates. Two different eye-tracking systems were used because the infant and undergraduate participants were tested in different laboratories. A corneal reflection technique was used to measure where specifically participants were looking as they watched the stimulus videos. The principle of the corneal reflection method is that an infrared light source mounted below the eye-tracking monitor is used to generate reflection patterns on the



corneas of the viewer's eyes. These reflection patterns are captured by a camera mounted below the eye-tracking monitor and are then used to calculate the three-dimensional position of each eyeball and, hence, where the participant is looking on the screen (i.e., the X and Y coordinates of the participant's gaze). The data rates (i.e., the rate at which the system collects gaze data) of the Tobii 1750 and T60 XL are 50Hz and 60Hz, respectively. This equates to 50 gaze data points per second for the 1750 (i.e., 1 data point every 20 ms) and 60 gaze data points per second for the T60 XL (i.e., 1 data point every 16.7 ms). Note that the use of eye-trackers with different sampling rates means that more data points were collected for undergraduates than infants. However, this difference has no effect on the overall pattern of data.

The average accuracy of both eye-tracking systems is in the range of 0.5 to 1 visual degree, which approximates to a 0.5 to 1 cm area on the screen with a viewing distance of 60 cm (i.e., the approximate viewing distance used in the current study). When both eyes cannot be measured (e.g., because of movement or head position), data from a single eye are used to determine the gaze coordinates. The eye-tracking systems compensate for robust head movements, which typically result in a temporary accuracy error of less than 1 visual degree. The Tobii 1750 and T60 XL recover from a complete tracking failure in less than 100 ms and 300 ms, respectively.

## **Stimuli**

### ***Eye-tracking stimuli***

With a 60-cm viewing distance, each of the  $22.86 \times 34.67$  cm video events measured  $10.79^\circ \times 16.34^\circ$  of vertical and horizontal visual angle, respectively. Despite the difference in the size of the Tobii 1750 and T60 XL monitors, the size and visual angle of the video stimuli were adjusted to be the same on both eye-trackers.

***Familiarization events.*** Participants saw one of two familiarization events (successful- or failed-reaching) that were identical to those in Study 1 (Figure 1a). Both events begin with a 1000 ms sequence in which the actor extends his neck to gaze over the barrier and fixate on the ball. He returns to his starting position and the reaching action begins.

In the *successful-reaching* event, the actor reaches over the barrier (with an arcing motion), grasps the ball, brings it back to his torso (tracing the same arcing motion), and

the video freezes. Throughout the reaching action the actor looks in the direction of his action and maintains a neutral expression. In the frozen state, the actor is holding the ball in his hand and looking down at it with a neutral expression.

In the *failed-reaching* event, the actor reaches over the barrier (with an arcing motion), but his reach falls short of the ball. His hand remains separated from the ball by 2 visual degrees (i.e., a distance of roughly 2 cm on the screen with a viewing distance of 60 cm). After hovering in this position with his hand over the ball, the actor brings his empty hand back to his torso and the video freezes. Throughout the reaching action the actor looks in the direction of his action and maintains a neutral expression. In the frozen state, the actor is looking down at his empty hand with an expression of disappointment.

Both reaching actions are 6000 ms in duration, followed by a 3000 ms freeze. The duration of the freeze was set at 3000 ms in order that the full length of the trials (10 s) would be comparable to the average duration of looking during habituation for participants in Study 1 ( $M = 9.68$  s). Note that the extended freeze segment also enabled an examination of retrospective processing of the reaching events after the actions were completed.

***Test events.*** Following familiarization, all participants were shown two test events (direct-reach, indirect-reach) that were identical to those in Study 1 (Figure 1b). In both events, the barrier is absent and the actor successfully grasps the ball. In the *direct-reach event*, the actor reaches directly (in a straight line) for the ball, grasps it, brings it directly back to his torso, and the video freezes. In the *indirect-reach event*, the actor reaches in an arcing path, grasps the ball, brings it back to his torso, and the video freezes. Throughout both reaches, the actor looks in the direction of his action and maintains a neutral expression. In the frozen state, the actor is holding the ball in his hand and looking down at it with a neutral expression.

Both reaching actions are 6800 ms in duration, followed by an 8200 ms freeze. The duration of the freeze was set at 8200 ms on the basis of results from Study 1. Typical global looking times to the test events in Study 1 ranged from roughly 5 to 12 s; however, some subjects looked considerably longer. To allow for differences in processing times related to the test events, the duration was set at 15 s. Note that this

extended freeze segment also enabled an examination of retrospective processing of the test events after the actions were completed.

***Stimulus timing.*** The ability to record participants' gaze location every 20 or 16.7 ms necessitates precise control of both the spatial and temporal properties of the eye-tracking stimuli. Thus, it is important to note that within each pair of video events (i.e., successful- and failed-reaching events; direct- and indirect reach events), events are of different durations for certain parallel segments. For example, in order for the actor's reach to travel the full distance to the ball and grasp it (in the successful-reaching condition) in the time it takes for the actor's reach to travel to a distance of 2 visual degrees from the ball (in the failed-reaching condition), the initial reaching motion of the successful reach occurs 400 ms faster than the initial reaching motion of the failed reach. In addition, the time it takes for the actor's reach to travel in an arcing motion to the ball (in the indirect-reach) is roughly 350 ms longer than the time it takes for the actor's reach to travel directly to the ball (direct-reach). The decision to allow this flexibility in the timing of the events was made during filming in order to ensure that the actions appeared fluid and natural instead of artificial and controlled. These timing differences are generally minor (i.e., in all cases less than 500 ms for the familiarization events and less than 850 ms for the test events) and were accounted for during the data reduction process (see Data Reduction and Analysis section).

## **Procedure**

### ***Experimental task***

Participants were positioned in front of the eye-tracking monitor at a viewing distance of approximately 60 cm. Infants were seated on a parent's lap and undergraduates sat independently. The eye height of each participant was aligned with the horizontal midline of the monitor by raising or lowering the monitor with the aid of an adjustable arm (Tobii 1750) or an adjustable desk mount (Tobii T60 XL).

Eye-tracker calibration and stimulus presentation were controlled by ClearView software (Tobii Technology, Stockholm, Sweden) and Tobii Studio software (Tobii Technology, Stockholm, Sweden) for infants and undergraduates, respectively. Before beginning the experimental task, the eye tracker was calibrated individually for each participant using a 5-point calibration procedure in which a red circular target was

presented sequentially against a white background at five locations on the screen (i.e., every corner and the center). The moving target readily captures participants' attention and, as they gaze to each of the fixation points, the eye-tracker measures characteristics of the participants' eyes that correspond to that gaze position. The calibration procedure was repeated until at least 3 of the 5 points were marked as being properly calibrated for each eye (see Gredebäck, Johnson, & von Hofsten, 2010 for details on the calibration procedure and criterion). Three participants (8-month-olds:  $n = 2$ ; 10-month-olds:  $n = 1$ ) who were unable to meet this criterion completed the study, but were excluded from the final data set.

In the experimental task, participants were presented with 16 reaching events: 10 successive repetitions of either the successful-reaching or the failed-reaching event (each 10 s in duration) followed by six test events (each 15 s in duration). All participants saw three repetitions of both the direct-reach and indirect-reach test events (in an alternating sequence and counterbalanced order). Reaching events were alternated with a brief animation (accompanied by music) that was designed to orient participants' attention to the screen. The attention-getting stimulus began immediately following each reaching event. When the participant was attending to the screen and the eye tracker was able to track both of the participant's eyes, the experimenter pressed a key to end the attention-getter and initiate the next event.

### ***Parent questionnaire***

Following the eye-tracking portion of the study, parents of the infant participants completed an 18-item questionnaire (see Appendix). This questionnaire was designed to provide a measure of motor and social behaviors infants produce in their daily lives that have been hypothesized to be related to intention understanding. The ultimate goal was to investigate how variability in infant behaviors (as assessed by this questionnaire) is related to variability in understanding intention (as revealed in the experimental task).

To provide a measure of motor development, four items assessed infants' self-locomotive development (i.e., the ability to crawl, stand, walk with support, and walk independently). Two additional items were created based on the literature on means-end behavior (e.g., Willatts, 1995). These items assessed infants' ability to produce behaviors that involve the deliberate and planful execution of a sequence of steps to achieve a goal

in situations where an obstacle prevents achieving that goal (e.g., removing a cover to search for a hidden object; see Appendix).

Twelve additional items assessed social behaviors related to joint attention. These items represented a range of behaviors including active behaviors (e.g., “Does your child use his/her index finger to point to indicate interest in something?”) as well as more responsive behaviors (e.g., “Does your child look at things you are looking at?”). Nine of these items were taken or modified from the Modified Checklist for Autism in Toddlers (M-CHAT™; Robins, Fein, & Barton, 1999; items are indicated in Appendix). The M-CHAT is an instrument validated for screening toddlers between 16 and 30 months of age, to assess risk for autism spectrum disorders. Because the infants in the current study were considerably younger than the children this instrument was designed for, variability on this measure was expected to reflect normative differences in the development of social understanding and relatedness as rated by a parent, and not risk for autism spectrum disorders. Two additional joint attention items were taken from the Communication and Symbolic Behavior Scales Development Profile Infant-Toddler Checklist (CSBS DP; Wetherby & Prizant, 1998, 2002; items are indicated in Appendix). The CSBS DP Infant-Toddler Checklist is a parent-report measure that is part of a larger measure assessing many different aspects of development in infants and toddlers between 6 and 24 months of age with the goal of early identification of delays in communicative, social-affective, and symbolic abilities. One final social item was created specifically for this questionnaire based on the literature on joint attention (“If you and your child are playing with an object together, does he/she look back and forth between you and the object?” e.g., Carpenter et al., 1998).

For all items, parents were instructed to indicate with an X whether their child performs each behavior “Often”, “Sometimes”, or “Not yet”. For the self-locomotive behaviors that children were producing, parents were also asked to indicate at what age their child began to do so. Two points were given for behaviors that occur “often”; 1 for behaviors that occur “sometimes”; and zero for behaviors that have not yet occurred.

### **Eye-Tracking Data Reduction and Analysis**

The data that the eye-tracker collects are the X and Y coordinates of participants’ point of gaze (i.e., where participants are looking on the screen) every 20 or 16.7 ms,

depending on the sampling rate of the eye-tracker (Tobii 1750: 50 Hz, 1 data point every 20 ms; Tobii XL T60: 60 Hz, 1 data point every 16.7 ms). Each sample that the eye-tracker collects is called a *gaze data point*. Text files containing these raw gaze data points were exported using the eye-tracking software system. The ultimate goal was to analyze these data in the form of the latency and proportion of looking to key elements of the reaching actions at key points during the video events. To do so, the following standard data reduction procedures were conducted (see Gredebäck et al., 2010): (1) defining areas of interest around key components of the reaching actions; (2) designating distinct segments in the video events; (3) filtering the data based on specific inclusion criteria; and (4) transforming the raw data to measures of the latency and duration of looking. Each of these procedures is described below.

### ***Areas of interest***

To enable analysis of where participants were looking (e.g., the actor, the ball) at any given time, areas of interest (AOIs) were defined manually around each target component of the video events. All AOIs were rectangular in shape, with the exception of those for the ball, which were circular. For all stationary targets, the edges of the AOIs subtended approximately 1 visual degree beyond the outer limits of the object. The rationale for including additional space beyond the outer limits of the object was to accommodate any slight inaccuracies in calibration and the small inaccuracies inherent in the eye-tracking system. The size of this space, 1 visual degree, was selected based on standards in the field (see Gredebäck et al., 2010) and estimates of the inaccuracies inherent in the Tobii eye-tracking systems (between 0.5 and 1 visual degree). Because of the dynamic nature of the stimuli, it was not possible to define precise AOIs around moving targets, such as the actor's hand and face. Instead, larger AOIs were defined to encompass the space through which these shifting targets move during the course of the reaching events.

The following AOIs were defined for the successful- and failed-reaching events (see Figure 5): (a) *Ball*: the ball in its initial location on the table; (b) *Head Space*: the space in which the actor's head moves during the course of the reaching events; (c) *Reach Space*: the space in which the actor's hand moves during the course of the reaching events (up to but not contiguous with the ball); (d) *Face*: the actor's face in its

frozen position following the completion of the reaching action; (e) *Ball-Hand*: the ball in its final position in the actor's hand following the completion of the reaching action in the successful-reaching event; and (f) *Empty Hand*: the actor's empty hand following the completion of the reaching action in the failed-reaching event. With the exception of the Ball-Hand and Empty Hand AOIs, each of the AOIs is the same size and shape in both the successful- and failed-reaching events.

Note that because of the manner in which the actor reached for the ball in the successful- and failed-reaching events (i.e., leaning forward and reaching in an arcing motion), the true spaces in which the actor's head and arm move overlap. However, because of the difficulty of analyzing and interpreting overlapping AOIs, the AOIs defined as Reach Space and Head Space do not overlap. This was done by excluding from the Reach Space AOI any space in which the actor's head moves. Therefore, estimates of looking to the Reach Space AOI are conservative and estimates of looking to the Head Space may include some looks to the actor's moving arm.

For the direct-reach and indirect-reach events, the following AOIs were defined (see Figure 6): (a) *Ball*: the ball in its initial location on the table (identical in size, shape, and location to the Ball AOIs in the successful- and failed-reaching events); (b) *Head Space*: the space in which the actor's head moves during the course of the reaching events; (c) *Straight Reach Space*: the space in which the actor moves his hand during the direct-reach event; (d) *Arcing Reach Space*: the space in which the actor moves his hand during the indirect-reach event (identical in size, shape, and location to the Reach Space AOIs in the successful- and failed-reaching events); (e) *Face*: the actor's face in its frozen position following the completion of the reaching action (identical in size and shape to the Face AOIs in the successful- and failed-reaching event); and (f) *Ball-Hand*: the ball in its position in the actor's hand following the completion of both the direct- and indirect-reach events (identical in size and shape to the Ball-Hand AOI in the successful-reaching event). Each of these AOIs except Head Space is identical in size and shape in both the direct- and indirect-reach events. The Head Space AOI is not matched across test events due to differences in the amount of head movement involved in arcing versus straight reaches.

Gaze data derived from the output of the eye-tracker were recoded in terms of these AOIs using Matlab.

### ***Video segments***

The video events were divided into 5 distinct segments that were intended to reflect intuitive boundaries in the events where features of the actor's movement change (see Zacks & Swallow, 2007 for a review of behavioral and neuroimaging data on this process of event segmentation).

The first is the *Peek* segment. Starting at the stimulus onset, this is the segment during which the actor extends his neck to gaze over the barrier at the ball and then returns to his starting position. Note that this segment is not a component of the direct- and indirect-reach events because, in the absence of the barrier in these events, the actor does not perform the peeking action.

The second segment, *Reach*, includes the period from when the actor begins reaching for the ball to when his hand is 2 visual degrees away from the ball. This is the point at which the hand plus 1 visual degree crosses into the Ball AOI in the successful-reaching condition and the point before which looks to the ball are considered anticipatory (see the Latency Analysis section below for more on this criterion for anticipatory looking).

The third segment is the *Grasp* segment. For the successful-reach, direct-reach, and indirect-reach events, this segment includes the time during which the actor's hand crosses (from 2 visual degrees away from the ball) into the Ball AOI, grasps the ball, and exits the Ball AOI. For the failed-reaching event, this segment includes the time during which the actor's hand hovers at 2 visual degrees away from the ball before it returns. Note that this segment does not strictly follow the natural boundaries in the event's movement; instead, it is defined empirically as the time during which action is taking place inside the Ball AOI.

The fourth segment, *Return*, includes the period during which the actor's hand (holding the ball or not) returns to its starting position. Finally, the last segment, *Freeze*, is the segment during which the actor remains frozen with the ball in his hand (successful-, direct-, and indirect-reach events) or not (failed-reach event). All segments with the exception of the Peek segment are included in each of the four reaching events.



### ***Inclusion criteria***

Prior to the focal examination of looking to specific AOIs during specific video segments, overall looking to the full screen was evaluated to determine whether inclusion criteria were met. Because the central analyses concern visual fixation patterns during the Peek and Reach segments, trials on which individual participants provided data (i.e., watched the full screen) for less than 50% of the Peek and Reach segments were excluded from that participant's data. Across participants, 13.6% of habituation trials and 9.5% of test trials were dropped for this reason. The number of trials dropped per subject did not differ significantly by age group or condition (all  $p$  values  $> .36$ ). Participants for whom 5 or more habituation trials were dropped were excluded from the final data set (8-month-olds:  $n = 2$ ; 10-month-olds:  $n = 1$ ; undergraduates:  $n = 3$ ).

### ***Data analyses***

To examine the focal hypotheses regarding patterns of looking during the familiarization and test events, two types of analyses were performed: latency and duration analyses. Data were processed differently for each kind of analysis. Descriptions of the data analysis and data processing procedures are provided below. To illustrate the patterns of results derived from both the latency and duration analyses, continuous plots were created showing participants' shifting gaze patterns over time. Descriptions of these plots and the data processing procedures they required are also provided below.

***Latency analyses.*** The first set of analyses examined the questions of when participants first looked at the ball and whether or not those looks were anticipatory. The dependent variable in these analyses was the onset of fixations to the Ball AOI. These analyses involved four important considerations.

***Defining fixations.*** The first consideration had to do with how to define a fixation. Fixations occur when eye-gaze pauses in a certain location. In the current study, fixations were defined as follows: (a) a minimum of 5 consecutive gaze data points located anywhere within the same AOI; or (b) a minimum of 10 gaze data points located in the same AOI within a window of 15 gaze data points. Recall that gaze data (i.e., the X and Y coordinates of the participant's gaze) are sampled every 20 or 16.7 ms and each gaze data point represents one sample that the eye-tracker collects. This means that the

minimum duration for a fixation was 100 ms for infants (since the Tobii 1750 samples every 20 ms) and 83.3 ms for undergraduates (since the Tobii T60 XL samples every 16.7 ms). Looks that did not meet these criteria were not included in the latency analyses (see Duchowski, 2007 for a discussion regarding defining fixations).

*No looks to the ball.* The second consideration in the latency analyses involved what to do with participants who did not look at the ball. For the latency analyses, participants who did not fixate the Ball AOI during the Peek, Reach, and Grasp segments were assigned fixation onset times equal to the end time of the Reach segment (i.e., 4400 ms). The rationale for this was as follows. The fact that a participant did not look at the ball at all during the Peek, Reach, and Grasp segments (but did attend to the event for at least 50% of those segments; see inclusion criteria) is important data that would otherwise be lost in the latency analyses. Assigning participants this late fixation onset score reflects their inattention to the ball while still allowing them to be included in the latency analyses. Participants who first looked at the Ball AOI only after the hand (in the failed-reaching event) or the hand and ball (in the successful-reaching event) exited the Ball AOI, were also assigned onset times equal to the end time of the Reach segment. This was done to account for differences between the successful- and failed-reaching events in whether or not the ball remained in the Ball AOI.

*Defining anticipatory looks.* A third consideration for the latency analyses is how to define whether a participant's latency of looking to the ball is anticipatory or not. Standard definitions of anticipatory looks are looks to the goal of the action before the action is completed (e.g., Falck-Ytter et al., 2006; Flanagan & Johansson, 2003; Gredebäck & Melinder, 2010; Gredebäck et al., 2009). This definition works for the successful-reaching action; however, because the goal is never fulfilled in the case of the failed-reaching condition (i.e., the hand never makes contact with the ball), this criterion required modification for the current study.

Here, anticipatory looks were defined as looks to the Ball AOI that occur before the actor's hand crosses the point of 2 visual degrees away from the ball. The benefit of using a criterion that involves a distance between the hand and the ball is that it can be applied equally to the successful- and failed-reaching events and, thus, can be equated across conditions. The distance of 2 visual degrees was selected for two reasons. First, 2

visual degrees is roughly the distance between the actor's hand and the ball during the Grasp segment of the failed-reaching event. Thus, this distance represents the smallest distance between the ball and the hand that applies to both reaching conditions. Second, 2 visual degrees represents the point at which a 1 visual degree buffer around the hand meets a 1 visual degree buffer around the ball. At this distance conclusions regarding whether a given look is to the ball or to the hand can be drawn with confidence, even given small inaccuracies inherent in the eye-tracking system (0.5 to 1 visual degree). Once the hand moves any closer to the ball, however, it becomes less clear whether a given look is to the ball or to the hand. Thus, in the current study, I define anticipatory looks as looks to the Ball AOI that occur before the hand reaches a distance of 2 visual degrees from the ball. Latency analyses were conducted both on this binary variable of anticipatory looking and on the continuous variable of latency of looking to the ball.

*Timing adjustments.* A final important consideration related to the latency analyses involves equating the timing of the video events. As mentioned previously, there are differences across the reaching events in the onset and duration of each of the video segments. For this reason, fixations in each video event occur on a slightly different scale. To allow for comparisons across events, the timing of the successful- and failed-reaching events was adjusted to the same scale and the timing of the direct- and indirect-reach events was adjusted to another scale. Adjustments were made on a segment-by-segment basis. First, the duration of each segment of each video was identified. Segments that were shorter in one reaching-event were then "extended" to the length of the equivalent segment in the corresponding reaching event. This was done by mathematically multiplying latencies for a slightly shorter event segment by a small percentage adjustment to equate it to the parallel, slightly longer segment.

To clarify this, consider the following example. The duration of the Reach segment in the successful reaching condition (2065 ms) was extended to match the duration of the Reach segment in the failed-reaching condition (2498 ms). Fixation latencies were then corrected to account for this change. For example, consider a participant whose first look to the ball in one trial of the successful-reaching event occurred 1729 ms into the Reach segment (337 ms before the end of the segment). Once corrected to be on the same timescale as the failed reaching event (by multiplying by a

factor of 1.2—the ratio of the longer (successful) Reach segment to the shorter (failed) Reach segment), this look occurred 2091.6 ms into the Reach segment (408.7 ms before the end of the segment). Note that this adjustment maintains the relative time after the beginning and before the end of the segment that the look takes place. Moreover, it does not alter whether a look is anticipatory or not. Instead, it merely shifts the look onto a scale that is comparable with the failed-reaching event. All latency analyses were performed on the adjusted fixation onset times.

It is important to note here that, although timing adjustments help to account for timing differences in the video events, these adjustments do not change the fact that participants experienced these timing differences while observing the video events. The most important timing difference for the sake of the arguments being made in this study is the difference between the times at which the actor's hand is 2 visual degrees from the ball—that is, the time which determines whether or not participants' looks are counted as anticipatory. In the successful-reaching condition, this point occurs roughly 400 ms earlier than the equivalent moment in the failed reaching condition. Thus, if you consider only the amount of time available between when the video begins and when the anticipatory look cut-off occurs, participants in the failed-reaching condition have a greater opportunity to produce an anticipatory look than do participants in the successful-reaching condition. Another way to think about this difference is that, for their looks to be considered anticipatory, participants in the successful-reaching condition have to shift their gaze to the ball faster than participants in the failed-reaching condition. Note that these differences work in favor of finding evidence of anticipatory looking in the failed-reaching condition because infants are given added time to look anticipatorily; however, since the same timing differences apply for each age group, they work against the hypothesis of finding age-related differences in performance in the failed-reaching condition.

Similar differences exist for the direct- and indirect-reach events. The point at which the hand reaches the ball in the direct-reach event occurs 340 ms earlier than the equivalent moment in the indirect-reach event. Thus, if you consider only the amount of time available between when the video begins and when the anticipatory look cut-off occurs, participants have a greater opportunity to produce an anticipatory look during the

indirect-reach event. However, because differences in anticipatory looking to the direct-versus indirect-reach events are not central to the hypotheses being tested in this study, this difference is not a major concern.

***Duration analyses.*** In addition to the latency analyses, the second set of analyses used in this study examined how participants distributed their attention among the key components of the video events—the actor’s face, the trajectory of the reaching action, and the goal object. The dependent variable in these analyses was the duration of looking to each of the AOIs during each of the video segments. Duration of looking was defined as the total amount of time participants spent looking within a given AOI during a particular video segment.

To account for variation in the amount of time participants spent looking at each video segment (as a result of looks away, fussiness, etc.), durations of looking within each AOI were converted to proportions out of the total duration of looking to the entire screen (per segment). Because proportions automatically convert the data to the same scale, no adjustments were necessary to account for imbalanced segment durations.

***Continuous plots of gaze data over time.*** To illustrate the patterns of results derived from the latency and duration analyses, continuous graphs were created showing participants’ shifting gaze patterns over time. By plotting gaze data at each time point (every 20 or 16.7 ms, infants and undergraduates, respectively), these figures make use of the rich, real-time data available through eye-tracking methodology and provide a dynamic picture of the time course of participants’ responses to the video stimuli.

To illustrate the results of the latency analyses, the cumulative proportion of trials on which participants looked at the Ball AOI was plotted by condition for each age group at each time point (every 20 or 16.7 ms). Cumulative plots were used to illustrate the running total of gaze shifts to the Ball AOI over time. The fixation rules and timing adjustments in place for the latency analyses were also applied here.

To illustrate the results of the duration analyses, the proportion of trials on which participants looked at each AOI (Head Space, Reach Space, Ball) during the Peek, Reach, and Grasp segments was plotted separately for each age group and condition at each time point (every 20 or 16.7 ms). Non-cumulative plots were used to illustrate shifting attention patterns between AOIs rather than accumulating looking to any one AOI. The

data presented in these plots were adjusted using the timing adjustments described above. Segments that were shorter in one reaching-event were “extended” to the duration of the matched segment so that the boundaries between segments were equivalent across segment pairs (segments in the successful- and failed-reaching events; segments in the direct- and indirect-reaching events).

### ***Data aggregation and imputation of missing values***

Preliminary analyses of latency and duration during the familiarization phase (i.e., during the 10 successful- or failed-reaching action trials) showed significant effects of trial (1-10) that were best captured by aggregating data over triads of trials (Triad 1: trials 2-4; Triad 2: trials 5-7; Triad 3: trials 8-10). The first trial was examined separately as an indicator of participants’ initial expectations about successful- and failed-reaching events and because only on Trial 1 did participants have no idea whether the actor’s reach would be successful or unsuccessful.

Preliminary analyses of latency and duration during the test phase (i.e., during the three direct-reach and three indirect-reach test trials) did not show effects of trial within test type (direct vs. indirect). Thus, in subsequent analyses, data were aggregated by test type. Note that this means that each unit of data from the familiarization phase naturally parallels each until of data from the test phase because, in both cases, units of analysis are averages across three trials.

Missing data for trials that were dropped for failure to meet the inclusion criteria were imputed by taking the mean of the remaining values in that triad (for the familiarization phase) or in that test type (for the test phase). If more than one value within a triad or test type was missing, that triad or test type was dropped from analyses.

## **Results**

Results will be presented as follows. First, analyses examining participants’ processing of intentional actions in the eye-tracking task are presented. Results of participants’ looking to the successful- and failed-reaching actions shown during the familiarization phase are presented, followed by results of looking to the direct- and indirect-reach events during the test phase. For each phase, two kinds of analyses are presented: (1) analyses examining whether participants produced anticipatory looks to the Ball AOI; (2) analyses of the duration of looking to the Ball, Head Space, and Reach

Space AOIs. For each type of analysis, continuous plots of participants' eye-movement data are presented to provide a dynamic picture of the time course of their responses to the video stimuli. Finally, analyses are presented exploring the association between intention understanding (as revealed in the eye-tracking task) and parent-report measures of infants' social and motor abilities.

### *Characterizing Participants' Processing of Intentional Actions in Real Time*

#### **Familiarization Phase**

To explore how 8-month-olds, 10-month-olds, and undergraduates processed the successful- and failed-reaching actions in real time, analyses were conducted examining whether participants produced anticipatory looks to the ball and how they distributed their attention among the key AOIs during the successful- and failed-reaching familiarization trials.

#### *Anticipatory looking and latency to the Ball AOI during the familiarization phase*

The first question of interest was whether or not participants across ages and conditions demonstrated an understanding of the goal-directedness of the reaching actions by producing anticipatory looks to the ball. Recall that anticipatory looks involve looking to the goal of the action before the action is completed (in the case of the current study, before the hand is 2 visual degrees from the ball). I predicted that, consistent with Study 1 and other eye-tracking research (e.g., Falck-Ytter et al., 2006), participants of all ages would produce predictive eye movements to the ball while observing the successful reaching event. In contrast, only 10-month-olds and undergraduates would do so during the failed reaching event.

*Familiarization Trial 1: Anticipatory looking.* To reveal how participants initially viewed the reaching events (before they witnessed a failed or successful outcome), Trial 1 data were examined. First, the binary variable of whether or not participants produced an anticipatory look to the ball on Trial 1 was analyzed. A chi-square test of goodness-of-fit confirmed that the percentage of participants producing predictive looks to the ball on Trial 1 varied by age group,  $\chi^2(2, N = 79) = 15.05, p = .021$ . More undergraduates (72.0%) than 8-month-olds (25.9%) and 10-month-olds (25.9%) produced anticipatory looks to the ball on Trial 1. Thus, whereas the majority of

undergraduates showed an immediate expectation that the actor's reach would be goal-directed, few 8- and 10-month-olds demonstrated this effect.

Further analyses were conducted for each age group comparing the percentage of participants producing an anticipatory look across conditions (successful-, failed-reaching). Results showed that for undergraduates, the percentage of participants producing anticipatory looks to the ball on Trial 1 did not differ by condition,  $\chi^2(1, N = 25) = 0.10, p = .75$  (69.2% and 75.0% for the successful- and failed-reaching conditions, respectively). For 8-month-olds,  $\chi^2(1, N = 27) = 2.79, p = .095$ , and 10-month-olds,  $\chi^2(1, N = 27) = 5.34, p = .021$ , however, condition differences were observed. Unexpectedly, infants in the failed-reaching condition were more likely to produce anticipatory looks on Trial 1 (41.7% and 46.2%, 8- and 10-month-olds, respectively) than those in the successful-reaching condition (13.3% and 7.1%). This finding should be interpreted in light of the subtle timing differences between the successful- and failed-reaching events. Recall that the time at which the actor's hand is 2 visual degrees away from the ball in the successful-reaching condition is roughly 400 ms earlier than the equivalent moment in the failed reaching condition. Thus, considering only the amount of time available between when the videos begin and when the anticipatory look cut-off occurs, participants in the failed-reaching condition had a longer opportunity to produce an anticipatory look than did participants in the successful-reaching condition. Note, however, that Trial 1 was the only trial on which infants produced more anticipatory looks in the failed- than in the successful-reaching condition; moreover, this pattern did not occur on any trial for undergraduates. Thus, although these differences in the timing of the video events influenced naive viewers' *initial* patterns of looking at the events (Trial 1), beyond Trial 1 these timing differences were no longer a concern.

***Familiarization Trial 1: Latency.*** To further examine patterns of looking on Trial 1, analyses on the continuous variable of latency of looking to the ball were also conducted. Unlike the anticipatory looking measure, the latency measure allows for comparisons of when participants first fixated on the ball without the use of arbitrary standards for "anticipation." Participants' latency of looking to the ball was entered into an ANOVA with age group (8-months-olds, 10-months-olds, undergraduates), condition (successful-reaching, failed reaching), and gender (male, female) as between-subjects



factors. Results showed only a significant main effect of age group,  $F(2,67) = 5.98$ ,  $p = .004$ ,  $\eta_p^2 = .15$ . Bonferroni-adjusted pairwise comparisons revealed that undergraduates ( $M = 2986.05$ ,  $SD = 1042.91$ ) looked to the ball earlier than did infants at both 8- ( $M = 3917.48$ ,  $SD = 1131.88$ ) and 10-months ( $M = 3827.01$ ,  $SD = 1033.53$ ), both  $p$  values  $< .05$ . Unlike in the anticipatory looking analyses, no difference was observed in the average latency of looking to the ball across conditions at any age. Using 3500 ms (the time at which the actor's hand is 2 visual degrees away from the ball) as a reference point, these latencies represent anticipatory looks to the ball on Trial 1 for undergraduates and reactive (i.e., non-anticipatory) looks to the ball for infants at both 8 and 10 months.

**Summary: Familiarization Trial 1.** Overall, these latency analyses provide a stark contrast between infants and undergraduates' Trial 1 looking patterns. Even on the very first trial, undergraduates produced anticipatory gaze shifts demonstrating their immediate expectation that the actor's movements would be directed toward the goal object. In contrast, the gaze shifts of 8-month-olds and 10-month-olds on the first trial were more reactive in nature. These results may suggest that (unlike undergraduates) 8- and 10-month-olds possess a fragile, initial understanding of goal-directed actions that is influenced, at least to some degree, by the familiarity of the context. In a novel context with a novel actor, infants do not show immediate expectations of goal-directedness.

**Familiarization Triads 1 to 3: Anticipatory looking.** The focal anticipatory looking and latency analyses concern looking patterns beyond the first trial (on familiarization Trials 2-10). The binary variable of whether or not participants produced an anticipatory look to the ball on these trials was assessed by computing the proportion of trials in which an anticipatory look occurred within each triad. Proportions of anticipatory looks were entered into an ANOVA with triad (Triad 1: trials 2-4, Triad 2: trials 5-7, Triad 3: trials 8-10) as a within-subject factor and age group (8-month-olds, 10-month-olds, undergraduates), condition (successful-, failed-reaching), and gender (male, female) as between-subjects factors. Results revealed a main effect of condition,  $F(1, 60) = 10.88$ ,  $p = .002$ ,  $\eta_p^2 = .15$ , as well as two significant interactions: triad by age group,  $F(4, 120) = 3.30$ ,  $p = .013$ ,  $\eta_p^2 = .099$ , and triad by condition,  $F(2,120) = 10.68$ ,  $p < .001$ ,  $\eta_p^2 = .15$ . These effects are best understood when qualified by a significant three-way interaction of triad, age group, and condition,  $F(4, 120) = 2.54$ ,  $p = .043$ ,  $\eta_p^2 = .08$ .

As can be seen in Figure 7, the interaction of triad by condition differed across age groups. As predicted, in the successful-reaching condition, the performance of 8-month-olds, 10-month-olds, and undergraduates was roughly equivalent. Across triads, no effects of age group were observed (all  $p$  values  $> .25$ ). Results also showed that as participants watched the actor repeatedly grasp the ball successfully, the proportion of anticipatory looks to the ball increased,  $F(2, 65) = 4.29, p = .018, \eta_p^2 = .12$ .

In contrast, in the failed-reaching condition, the pattern of results varied by age group and triad. There were pronounced age group differences in the proportion of predictive looks to the ball during the first triad,  $F(2, 60) = 5.02, p = .010, \eta_p^2 = .14$ . As Figure 7 illustrates, in Triad 1, 8-month-olds in the failed-reaching condition produced significantly fewer anticipatory looks to the ball than did 10-month-olds and undergraduates. The proportion of anticipatory looks produced by 8-month-olds remained at this low level across triads,  $F(2, 59) = 0.79, p = .46, \eta_p^2 = .03$ . A different pattern of results was observed for 10-month-olds and undergraduates. As participants in both age groups watched the actor fail repeatedly, anticipatory looks to the ball decreased (10-month-olds:  $F(2, 59) = 4.04, p = .023, \eta_p^2 = .12$ ; undergraduates:  $F(2, 59) = 6.63, p = .003, \eta_p^2 = .18$ ).

These anticipatory looking results suggest that, although participants of all ages viewed the successful-reaching action as directed toward the ball (and increasingly so over time), only 10-month-olds and undergraduates recognized the goal-directedness of the failed-reaching action. It is also important to note that 10-month-olds and undergraduates recognized the goal-directedness of the failed-reaching action very quickly—in the first triad (trials 2-4). After that, they learned (over repeated trials) that the agent would not get the ball and, thus, ceased to produce anticipatory looks.

One crucial issue in these anticipatory looking analyses is the question of what defines an anticipatory look. In the prior analyses, anticipatory looks to the ball were defined as looks to the Ball AOI that occurred before the hand was a distance of 2 visual degrees away from the ball. However, strictly speaking, in the failed-reaching condition *all* looks to the ball during the Peek, Reach, and Grasp segments are anticipatory in nature, as the actor never actually reaches the ball. One possible explanation for the low levels of anticipatory looking by 8-month-olds in the failed reaching condition is that 8-

month-olds were simply slower to fixate on the ball than older infants and undergraduates and, thus, fewer of their looks met the criterion to be anticipatory. Note, however, that this is unlikely given that 8-month-olds are able to meet the criterion for anticipatory looking in the successful-reaching condition and (because of subtle differences in the timing of the reaching events) participants in the successful-reaching condition had to shift their gaze to the ball faster than those in the failed-reaching condition for their looks to be considered anticipatory.

Nevertheless, to further examine this possibility, analyses were conducted using the more generous rule that any looks to the ball during the Peek, Reach, and Grasp segments of the failed-reaching condition are predictive. A chi-square test of goodness-of-fit was performed comparing the percentage of participants at each age group who never look to the ball in Triad 1. Results showed a marginal effect of age group,  $\chi^2(2, N = 39) = 5.22, p = .073$ . Most notably, significantly more 8-month-olds (53.4%) than 10-month-olds (14.3%) never looked within the Ball AOI during the Peek, Reach, and Grasp segments in any of the three trials in Triad 1,  $\chi^2(1, N = 27) = 4.75, p = .029$ . These results indicate that, even when using the less conservative definition that *any* looks to the ball in the failed-reaching condition are anticipatory, 8-month-olds still show a different pattern of results than 10-month-olds and undergraduates, with many fewer looks to the ball, in spite of the fact that the agent's hand always approached the ball very closely (i.e., only failed to reach it by 2 visual degrees).

***Familiarization Triads 1 to 3: Latency.*** The continuous variable of latency of looking to the ball on Trials 2-10 was also examined. To reiterate, an important benefit of this analysis is that it allows for comparisons of the time at which participants first fixated within the Ball AOI without relying on a predetermined definition of anticipatory looking. To explore participants' latency of looking to the ball, an ANOVA with triad (Triad 1, Triad 2, Triad 3) as a within-subject factor and age group (8-month-olds, 10-month-olds, undergraduates), condition (successful-, failed-reaching), and gender (male, female) as between-subjects factors was performed. Overall, results corroborated those observed in the anticipatory looking analyses. Results showed a main effect of condition,  $F(1,60) = 14.00, p < .001, \eta_p^2 = .19$ , and an interaction of triad by condition,  $F(2, 120) =$

9.38,  $p < .001$ ,  $\eta_p^2 = .14$ , that are best understood when qualified by a significant three-way interaction of triad, age group and condition,  $F(4, 120) = 3.74$ ,  $p = .007$ ,  $\eta_p^2 = .11$ .

As seen in Figure 8, the effect of condition varied by triad and age group. Consider first the older infants and undergraduates. In Triad 1, these participants looked to the ball before the hand arrived at it in both the successful- and the failed-reaching conditions. Bonferroni-adjusted pairwise comparisons revealed no effects of condition on latency to the ball in the first triad for 10-month-olds or undergraduates (both  $p$  values  $> .89$ ). Over time, however, older infants and undergraduates differentiated their responses to the successful- and failed-reaching conditions as evidenced by a significant effect of condition at both ages in Triads 2 and 3 (all  $p$  values  $< .05$ ). As Figure 8 shows, in the successful-reaching condition, older infants and undergraduates continued to produce anticipatory looks to the ball throughout the familiarization phase. In contrast, in Triads 2 and 3 of the failed-reaching condition (after watching the actor fail repeatedly), 10-month-olds and undergraduates stopped producing anticipatory looks and showed significantly later latencies to the ball, revealing an increasing tendency to realize the agent systematically fails to grasp the object.

The pattern of results for 8-month-olds was very different. For these younger infants, the effect of condition was present in all three triads (Triads 1 and 2, both  $p$  values  $< .05$ ; Triad 3,  $p = .10$ ). As seen in Figure 8, in the successful condition, 8-month-olds looked to the ball before the hand arrived at it throughout the familiarization phase (after the first trial). In the failed condition, however, this was not the case: 8-month-olds produced significantly later looks to the ball in all three triads and, unlike even 10-month-olds, did not evidence any increasing tendency to ignore the ball.

***Familiarization Triads 1 to 3: Continuous plots of fixations to the Ball AOI.*** To further illustrate the condition by age group interaction in the time at which participants first fixated the ball, cumulative plots of the onset of participants' fixation to the Ball AOI during the Peek and Reach segments were created. Cumulative plots were used to illustrate the running total of gaze shifts to the ball over time. The data from Triad 1 were used as this triad showed the most pronounced effects. In Figure 9, the cumulative proportion of trials on which participants looked at the Ball AOI is plotted by condition

for each age group at each time point (every 20 or 16.7 ms, infants and undergraduates, respectively). Error bars represent standard error over participants.

As is clearly demonstrated by the overlapping error bars during the Reach segment (1000 to 3500 ms), the gaze patterns of 10-month-olds and undergraduates were not differentiated by condition: 10-month-olds and undergraduates shifted their attention to the ball in the same manner regardless of whether the reaching action was successful or unsuccessful. Moreover, at the time at which the actor's hand was 2 visual degrees away from the Ball AOI (3500 ms), participants had fixated the ball at roughly equal proportions across conditions. This was not the case for 8-month-olds. Figure 9 shows that, at all points during the Reach segment, the proportion of trials on which 8-month-olds in the successful-reaching condition fixated the ball exceeded that of 8-month-olds in the failed-reaching condition.

***Summary: Anticipatory looking and latency to the Ball AOI during the familiarization phase.*** In sum, both anticipatory looking and latency analyses converge to demonstrate significant differences in how 8-month-olds, 10-month-olds, and undergraduates process successful- and failed-reaching actions in real time. As predicted, participants of all ages produced anticipatory looks to the ball when the actor successfully retrieved it—suggesting that as early as 8 months, infants understand the goal-directedness of successful actions. In the case of failed actions, however, 8-month-olds showed a unique pattern of results. Whereas 10-month-olds and undergraduates initially produced anticipatory looks to the ball even when the actor failed to grasp it, 8-month-olds did not show this effect. With increasing trials, 10-month-olds and undergraduates looked as if they increasingly expected the agent would *not* grasp the ball. Eight-month-olds did not show this effect, as if in the failed-reaching condition they failed to form any expectation about the ball, neither initially in the first triad, nor later across the remaining trials. Together, these data are consistent with the hypothesis that an understanding of the goal-directedness of failed actions is present by 10- but not 8-months of age.

***Duration of looking to the Ball, Head Space, and Reach Space AOIs during the familiarization phase***

Given the focal findings concerning the ball (i.e., the goal object), a second key question concerns how participants distributed their attention among the other key

components of the successful- and failed-reaching events—the actor’s face and the trajectory of the reaching action, as well as the goal-object. Participants’ relative attention to these AOIs was examined separately during the Peek and Reach, Grasp, and Freeze segments.

These analyses were motivated by two key goals. The first was to confirm that participants of all ages (even the youngest infants) were following the flow of the events appropriately by shifting their attention among the various AOIs during the course of the actions. The second goal was to evaluate the microstructure of participants’ looking patterns. On the assumption that visual processing reflects cognitive processing, informative differences in how older versus younger participants visually process these events could reveal key insights into how participants of different ages are interpreting intentional actions. In particular, I predicted that 8-month-olds would show a qualitatively different pattern of visual processing than 10-month-olds and undergraduates.

***Peek and Reach segments.*** First, the proportion of time participants spent looking within each of the key AOIs before the Grasp segment (during the Peek and Reach segments; 0 to 3500 ms) was entered into an ANOVA with Triad (Triad 1, Triad 2, Triad 3) and AOI (Ball, Head Space, Reach Space) as within-subject factors and age group (8-month-olds, 10-month-olds, undergraduates), condition (successful-reaching, failed reaching), and gender (male, female) as between-subjects factors.

First, results revealed two effects related to triad: a main effect,  $F(2, 132) = 3.95$ ,  $p = .022$ ,  $\eta_p^2 = .056$ , and a three-way interaction of triad, AOI, and condition,  $F(4, 264) = 4.95$ ,  $p = .001$ ,  $\eta_p^2 = .070$ . These effects are best explained by a pattern of increased attention to the Ball AOI,  $F(2, 66) = 7.46$ ,  $p = .001$ ,  $\eta_p^2 = .18$ , and decreased attention to the Head Space AOI,  $F(2, 66) = 6.35$ ,  $p = .003$ ,  $\eta_p^2 = .16$ , across triads in the successful-reaching condition. Results suggest a shift in attention from the actor to the actor’s goal after repeated observations of action success. No significant differences across triads were observed in the failed-reaching condition.

Results also revealed a large main effect of AOI,  $F(2, 132) = 308.78$ ,  $p < .001$ ,  $\eta_p^2 = .82$ , as well as significant two-way interactions of AOI by age group,  $F(4, 132) = 3.88$ ,  $p = .005$ ,  $\eta_p^2 = .11$ , and AOI by condition,  $F(2, 132) = 6.60$ ,  $p = .002$ ,  $\eta_p^2 = .091$ . Data

showed that, overall, participants spent the majority of time looking at the Head Space AOI ( $M = .56$ ) and considerably less time looking at the Reach Space ( $M = .15$ ) and Ball ( $M = .083$ ) AOIs. (An interpretation of the somewhat unexpected amount of attention to the Head Space AOI is offered later in the section in which continuous plots of looks to the Ball, Head Space, and Reach Space AOI are discussed). These AOI effects were observed at all ages; however, the specific proportion of looking to each of the AOIs varied moderately by age group. For example, undergraduates showed significantly more looking to the ball ( $M = .12$ ) than did 8-month-olds and 10-month-olds ( $M_s = .063$  and  $.069$ , respectively;  $p = .024$ ) suggesting that undergraduates' interpretations of the successful- and failed-reaching actions were largely more centered on the ball than were those of younger participants. In addition, there was a linear effect of age group in attention to the Head Space AOI, ( $p = .007$ ), with 8-month-olds showing the greatest proportion of looking to the actor's face ( $M = .62$ ), followed by 10-month-olds ( $M = .56$ ) and then undergraduates ( $M = .50$ ). These results indicate that the actor's face and head were especially attention-getting for younger infants. Finally, undergraduates and 10-month-olds looked longer at the Reach Space AOI ( $M_s = .18$  and  $.15$ , respectively) than did 8-month-olds ( $M = .12$ ;  $p = .016$ ).

Overall, patterns in attention during the Pre-Grasp segments reveal only modest age differences in attention to the three key AOIs. In particular, although 8-month-olds attended relatively more to the actor and relatively less to the reach and the goal object, no major revealing differences were observed.

**Grasp segment.** Next, to evaluate patterns of attention when the successful- and failed-reaching actions were maximally dissimilar, analyses were conducted examining attention to the key components of the reaching actions during the Grasp segment (3501 to 4833 ms). Recall that in the successful-reaching condition, grasping means actually grasping the ball before its ultimate retrieval. In the failed-reaching condition, "grasping" means the actor's hand falling short of the ball, albeit in an open-grasp position with fingers directed at the ball.

The proportion of time participants spent looking within each of the three key AOIs during the Grasp segment was entered in an ANOVA with Triad (Triad 1, Triad 2, Triad 3) and AOI (Ball, Head Space, Reach Space) as within-subject factors and age

group (8-month-olds, 10-month-olds, undergraduates), condition (successful-reaching, failed reaching), and gender (male, female) as between-subjects factors. Results revealed significant main effects of AOI,  $F(2, 130) = 22.37, p < .001, \eta_p^2 = .26$ , age group,  $F(2, 65) = 4.66, p = .013, \eta_p^2 = .13$ , and condition,  $F(1, 65) = 21.73, p < .001, \eta_p^2 = .25$ , as well as interactions of AOI by age group,  $F(4, 130) = 3.14, p = .017, \eta_p^2 = .088$ , AOI by condition,  $F(2, 130) = 12.40, p < .001, \eta_p^2 = .16$ , and triad by AOI,  $F(4, 260) = 4.28, p = .002, \eta_p^2 = .062$ .

The effects and interactions of AOI, age group, and condition are best interpreted by considering the AOI by condition interaction. Results indicated that participants in the successful-reaching condition differentiated among the AOIs during the Grasp segment,  $F(2, 64) = 28.69, p < .001, \eta_p^2 = .47$ , showing significantly more attention within the Ball AOI ( $M = .54$ ) than either the Head Space ( $M = .15$ ) or the Reach Space ( $M = .14$ ) AOIs. This pattern of results was expected given that the action during Grasp segment was centered in and around the Ball AOI. In the failed-reaching condition, however, participants distributed their attention equally among all three AOIs during the Grasp segment,  $F(2, 64) = 0.68, p = .51, \eta_p^2 = .02$ . They did not show a significant preference to look at the Ball ( $M = .25$ ), Head Space ( $M = .17$ ), or Reach Space ( $M = .21$ ) AOIs, suggesting that participants varied in where they attended when the actor failed to grasp the ball. Not surprisingly, participants who saw the actor's hand enter the Ball AOI and make contact with the ball (i.e., in the successful-reaching condition) looked significantly longer within the Ball AOI than did participants in the failed-reaching condition,  $F(1, 65) = 26.97, p < .001, \eta_p^2 = .29$ . This general pattern of results was consistent across age groups, although 10-month-olds showed the most differentiation among AOIs in both conditions. Finally, as suggested by the interaction of triad and AOI, differentiation among the AOIs decreased across triads, likely due to loss of interest over time.

Overall, these results suggest that participants of all ages (even 8-month-olds) were attentive to the key difference between the two conditions: that is, in the successful-reaching condition the actor successfully made contact with the ball, and in the failed-reaching condition he did not.

**Freeze segment.** Finally, analyses were also conducted examining attention to the key AOIs during the Freeze segment at the very end of the events, when the hand



(with or without the ball) had returned to the agent's body and the reaching action was complete. This segment was predicted to provide insight into participants' retrospective reasoning about the successful- and failed-actions after they were complete.

In order to compare across conditions despite differences in the actor's situation when the video freezes (i.e., the actor holding the ball in his hand in the successful-reaching condition, and the actor's empty hand with the ball still on the table in the failed-reaching condition), analyses were conducted comparing the proportion of time participants spent looking at the actor's face versus the AOIs related to the ball (i.e., the ball in the actor's hand in the successful-reaching condition and both the actor's empty hand and the ball on the table in the failed-reaching condition). This collection of AOIs related to the ball is referred to as Ball Plus.

An ANOVA was performed with Triad (Triad 1, Triad 2, Triad 3) and AOI (Ball Plus, Face) as within-subject factors, and age group (8-month-olds, 10-month-olds, undergraduates), condition (successful-reaching, failed reaching), and gender as between-subjects factors. Results revealed a significant main effect of AOI,  $F(1, 61) = 13.85, p < .001, \eta_p^2 = .19$ , and a marginal interaction of AOI by condition,  $F(1, 61) = 3.32, p = .073, \eta_p^2 = .052$ . Overall, during the Freeze segment, participants looked significantly longer at the actor's face than at the ball and the actor's empty hand (failed-reaching condition) or at the ball in the actor's hand (successful-reaching condition). This effect was more pronounced in the failed- ( $M_{face} = .44; M_{ball\ plus} = .24$ ) than in the successful- ( $M_{face} = .38; M_{ball\ plus} = .31$ ) reaching condition and was consistent across age groups. One explanation for the more pronounced face preference in the Freeze segment of the failed-reaching condition is that the actor's face is more expressive following reach failure (i.e., the actor appears disappointed) than following reach success (i.e., the actor appears neutral). A distinct possibility is that participants in the failed-reaching condition looked relatively longer at the actor's face in search of an explanation for the failed attempt. Finally, condition differences could also reflect increased interest in the ball (and, hence, decreased interest in the actor's face) following the actor's success. Any or all of these explanations may be at play.

Overall, patterns of attention to the Ball, Head Space, and Reach Space AOIs during various segments of the successful- and failed-reaching events indicate subtle

interpretable age and condition differences. Nonetheless, these patterns of looking do not seem to support the view that younger infants process the major components of the visual events in vastly different ways.

*Continuous plots of looks to the Ball, Head Space, and Reach Space AOIs during the familiarization phase.* Finally, to shed further light on how participants shifted their attention among the key AOIs as the reaching events unfolded over time, the proportion of trials on which participants looked at each AOI (Head Space, Reach Space, Ball) during the Peek, Reach, and Grasp segments was plotted separately for each age group and condition at each timestamp (see Figure 10). Non-cumulative plots were chosen to illustrate shifting attention between AOIs rather than accumulating looking to any one AOI. Because the previous analyses revealed no clear effects of triad, data from all three triads were incorporated. Finally, to minimize visual clutter, standard errors were not displayed on the plots. Note that because all trials (that met the general inclusion criteria) provided data points for these plots, the standard errors were extremely small.

Consider, first, the overall picture across age groups and conditions. These plots indicate that participants in both conditions were following the flow of events as would be expected—shifting their attention from the actor, to his reach, to the ball. This pattern was consistent across age groups suggesting that even 8-month-olds and 10-month-olds were tracking the events appropriately.

The plots in Figure 10 also help to elaborate the pattern of results observed in the previous analyses. First, the main effect of AOI during the Peek and Reach segments (0 to 3500 ms) can be seen. The Head Space AOI was clearly the dominant AOI during these segments. These plots provide a possible explanation for the high levels of attention to the Head Space AOI during the Reach segment. Recall that there is considerable overlap between the space in which the actor's hand and head move during the reaching actions. For the purpose of these analyses, this shared space was included in the Head Space AOI as it is the location in which the actor's head appears during the Grasp segment of the video. However, during the Reach segment, this space is also the location in which the initial arcing reach occurs. Although based on the current data it is impossible to say definitively whether attention to the Head Space AOI during the Reach

segment represents attention to the actor's face or to the reaching action, one likely possibility is that the second peak in attention to the Head Space AOI occurring at roughly 1500 ms across age groups and conditions (see Figure 10) actually represents attention to the actor's hand as it moves from its starting position up and over the barrier. On this view, the shift in attention that appears at roughly 2500 ms from the Head Space to the Reach Space AOI actually indicates the point at which participants track the actor's hand into the space defined as the Reach Space AOI—not a shift in attention from the actor to the reach. This possibility is likely given that the actor's hand enters the Reach space AOI at roughly 2300 ms.

If this interpretation is correct, then the current analyses may provide an inflated estimate of participants' attention to the actor's face; the dominant focus of attention during the Reach segment may actually be the actor's moving hand, not the actor's face. Moreover, age differences observed in attention to the Reach Space AOI during the Peek and Reach segments (namely less attention in 8-month-olds as compared to older infants and undergraduates) may actually be related to the speed with which participants at different ages move their eyes. For example, 8-month-olds may be slower to shift their gaze to the Reach Space AOI from the overlapping area in the Head Space AOI (e.g., Gredebäck, Ornkloo, & von Hofsten, 2006). As a result, 8-month-olds may show relatively less attention to the Reach Space AOI than their older peers. Unfortunately due to this overlap, strong conclusions about differential patterns of attention to the Reach Space and Head Space AOIs cannot be drawn.

The continuous plots in Figure 10 also illustrate the interactions of AOI by age group and condition during the Peek and Reach segments (0 to 3500 ms). Consider first the interaction of AOI by age group. The linear effect of age group in attention to the Head Space AOI can be seen: 8-month-olds showed the greatest attention to the Head Space AOI, followed by 10-month-olds and undergraduates. Age effects in attention to the Ball AOI can also be seen: undergraduates showed significantly more looking to the ball during the Peak and Reach segments than did 8- and 10-month-olds. Consider, also, the interaction of AOI by condition during the Peek and Reach segments. The plots in Figure 8 demonstrate that attention to the Ball AOI is greater for participants in the successful-reaching condition whereas attention to the Reach Space AOI is greater for

participants in the failed-reaching condition. These effects of condition can be seen across age groups.

Finally, the plots in Figure 10 provide a further illustration of the interaction of condition by AOI during the Grasp segment (3501-4833 ms). As demonstrated by the distinct peak in attention to the Ball AOI, the plots of the successful-reaching condition show that participants of all ages clearly differentiated among the AOIs—showing significantly more attention to the Ball AOI than either the Head Space or Reach Space AOIs during the Grasp segment. In contrast, participants in the failed-reaching condition looked considerably less at the ball and showed little differentiation in their attention to these AOIs.

***Summary: Duration of looking to the Ball, Head Space, and Reach Space AOIs during the familiarization phase.*** Overall, the relative duration analyses together with the continuous plots of looking to the Ball, Head Space, and Reach Space AOIs help to clarify how 8-month-olds, 10-month-olds, and undergraduates shifted their attention among the key AOIs as the successful- and failed-reaching events unfolded over time. Three general conclusions can be drawn from these findings. First, even participants as young as 8 months of age followed the flow of the reaching events appropriately by shifting their attention from the actor, to his reach, to the ball. This overall pattern of looking was remarkably consistent across age groups and conditions, confirming that the youngest infants experienced no general processing difficulties when observing these events.

Second, despite similarities in participants' overall flow of attention, condition differences were clear in the relative attention participants paid to the key AOIs. Attention patterns during the Grasp segment showed that participants at all ages were attentive to the main difference between the two conditions—that in the successful-reaching condition the actor successfully made contact with the ball and in the failed-reaching condition he did not. Moreover, participants' recognition of the outcome of the action was also evident in their processing of the events leading up to the Grasp segment.

Finally, an unexpected result was that 8-month-olds in the failed-reaching condition did not show a pattern of looking that was qualitatively different from that of participants in other age groups and conditions. Thus, the duration data did not provide

especially informative insight into how older versus younger participants are differentially interpreting intentional actions.

### **Test Phase**

Recall that following familiarization with the successful- or failed-reaching events, participants were presented with two test events in which the barrier was absent and the actor was shown successfully reaching for the ball either directly (in a straight line) or indirectly (in an arc). Evaluating infants' and undergraduates' responses to these test events offers an additional measure of (1) how participants processed the successful- and failed-reaching events, (2) what they predicted the actor would do when the barrier was gone, and (3) how they interpreted the actor's behavior in a different context.

In particular, one important question was how 10-month-olds and undergraduates in the failed reaching condition would respond to the test events. Recall that, by the end of the familiarization phase, 10-month-olds and undergraduates no longer produced anticipatory looks to the ball—suggesting that they had learned that the actor was unable to achieve his goal. However, if 10-month-olds and undergraduates maintained the view that the actor's reach was goal-directed and merely adjusted their expectations based on his record of failure, then in the new context of the test events they should have revised their expectations about the actor's behavior. That is, when they saw the actor in a new context where the barrier was gone and his reach could be successful, they should have appropriately updated their expectations and demonstrated those expectations through anticipatory looks.

Another important question was how 8-month-olds in the failed-reaching condition would perform given that they did not show evidence that they interpreted the actor's reaching action as goal-directed during familiarization. One possibility is that, as in the familiarization phase, 8-month-olds in the failed-reaching condition would not show evidence that they interpreted the direct- and indirect-reach events as goal-directed by failing to produce anticipatory looks. An alternative possibility is that 8-month-olds would fail to show anticipatory looks on the initial test trial; however, after seeing a successful outcome in the first test event (direct- or indirect-reach), they would slowly revise their interpretation and begin to anticipate the actor's connection with the goal object.

Lastly, recall that Study 1 drew conclusions about infants' understanding of goal-directedness from comparisons of global measures of looking to these direct and indirect test events. The eye tracking methodology employed here enables me to examine looking to these test events at a finer level of detail. Thus, a final question of interest was whether evaluating participants' looking to these test events as they unfolded over time could further explain why participants in Study 1 looked longer during the indirect-than the direct-reach test event (10- and 12-month-olds in the failed-reaching condition; 8-, 10-, and 12-month-olds in the successful-reaching condition). One possibility is that participants who identified the habituation event as directed toward the goal would be confused by the arcing trajectory of movement in the absence of the barrier and hence slower to look to the ball in the indirect-reach event. Confused participants may also spend more time puzzling on the actor's face following the indirect- than the direct-reach event. Either or both of these patterns could explain infants' longer looking to the indirect reach in Study 1.

#### ***Anticipatory looking and latency to the Ball AOI during the test phase***

***Test phase: Anticipatory looking.*** The first question of interest was whether or not participants across ages and familiarization conditions demonstrated an understanding of the goal-directedness of the test events by producing anticipatory looks to the ball. The binary variable of whether or not participants produced anticipatory looks to the ball during the test events was examined by computing the proportion of trials in which an anticipatory look occurred for each kind of test event. Proportions of anticipatory looks were entered into an ANOVA with test type (direct-reaching, indirect-reaching) as a within-subject factor and age group (8-month-olds, 10-month-olds, undergraduates), familiarization condition (successful-, failed-reaching), gender (male, female), and test order (direct-indirect, indirect-direct) as between-subjects factors.

Analyses revealed significant main effects of age group,  $F(2, 63) = 5.42, p = .007, \eta_p^2 = .15$ , and condition,  $F(1, 63) = 5.29, p = .025, \eta_p^2 = .078$ , that are best understood when qualified by an interaction of age group and condition,  $F(2, 63) = 3.57, p = .034, \eta_p^2 = .10$ . As Figure 11 shows, the effect of age group varied by condition. After familiarization with a successful-reaching event, participants of all ages showed equal proportions of anticipatory looks during the test events,  $F(2, 64) = .58, p = .57$ .

In contrast, after familiarization with a failed-reaching event, age group differences were observed,  $F(2, 64) = 9.27, p < .001, \eta_p^2 = .23$ . Eight-month-olds in the failed-reaching familiarization condition showed significantly fewer anticipatory looks during the test events than did 10-month-olds and undergraduates in the same condition (both  $p$  values  $< .003$ ). Likewise, whereas 10-month-olds and undergraduates in the successful- and failed-reaching conditions showed equal proportions of anticipatory looks during the test events, 8-month-olds who saw the actor successfully achieve his goal during familiarization produced significantly more anticipatory looks in the new context of the test events than did those who saw the actor fail repeatedly,  $F(1, 64) = 16.01, p < .001, \eta_p^2 = .20$ . Importantly, the pattern of anticipatory looking described here was consistent across both the direct- and the indirect-reach test events. Participants were equally likely to produce anticipatory looks in the direct and indirect reach events.

These anticipatory looking results suggest that, as predicted, participants of all ages who were familiarized with the successful-reaching action viewed the direct- and the indirect-reach actions in the new test context as directed toward the ball. Ten-month-olds and undergraduates familiarized with the failed-reaching condition also recognized the goal-directedness of the test events. These data suggest that, despite having learned during familiarization (after multiple failed outcomes) that the actor would not retrieve the ball, when 10-month-olds and undergraduates saw the actor in a new context they appropriately updated their expectations and again predicted that his behavior would be goal-directed. In contrast, as in the familiarization phase, 8-month-olds in the failed-reaching condition did not show evidence that they interpreted the direct- and indirect-reach events as goal-directed and rarely produced anticipatory looks during the test events.

***Test phase: Latency.*** Next, analyses on the continuous variable of latency of looking to the ball during the direct- and indirect-reach test events were conducted. Recall that an important benefit of the latency analyses is that they allow for comparisons of the time at which participants first fixated within the Ball AOI without relying on a predetermined definition of anticipatory looking. Participants' latency of looking to the ball was entered into an ANOVA with test type (direct-reach, indirect-reach) as a within-subject factor, and age group (8-month-olds, 10-month-olds, undergraduates),

familiarization condition (successful-reaching, failed reaching), gender (male, female), and test order (direct-indirect, indirect-direct) as between-subjects factors.

Results from the latency analyses were consistent with those of the anticipatory looking analyses. Significant main effects of both age group,  $F(2, 63) = 5.42, p = .007, \eta_p^2 = .15$ , and condition,  $F(1, 63) = 5.29, p = .025, \eta_p^2 = .08$ , were identified as well as a significant interaction of age group by condition,  $F(2, 63) = 3.57, p = .034, \eta_p^2 = .10$ . As seen in Figure 12, an effect of age group was observed only after familiarization with the failed-reaching event,  $F(2, 63) = 8.08, p = .001, \eta_p^2 = .20$ . In this condition, 8-month-olds looked to the ball in the test events significantly later than did 10-month-olds and undergraduates (both  $p$  values  $< .01$ ). That is, whereas 10-month-olds and undergraduates' looks to the ball were generally anticipatory in nature, 8-month-olds' were not. In contrast, for participants familiarized with the successful-reaching event, there were no age differences in the time at which participants' gaze arrived at the ball,  $F(2, 63) = 0.34, p = .71$ . Eight-month-olds, 10-month-olds, and undergraduates in the successful-reaching familiarization condition all produced equally anticipatory looks in the test events.

Results also showed a main effect of test type,  $F(1, 63) = 6.88, p = .011, \eta_p^2 = .098$ . Overall, participants' latency of looking to the ball was almost 300 ms faster for the direct-reach ( $M = 2366$ ) than for the indirect-reach ( $M = 2634$ ) test event. This result provides preliminary evidence that, when watching the indirect-reach event, participants were confused by or took longer to process the arcing trajectory of movement in the absence of the barrier and, hence, produced slower looks to the ball. However, these results must be interpreted in light of an interaction of test type by test order,  $F(1, 63) = 5.39, p = .023, \eta_p^2 = .079$ . This effect was only significant when the direct-reach event was the first test event participants observed,  $F(1, 63) = 12.39, p = .001, \eta_p^2 = .16$ . No such effect was found for the indirect-direct test order,  $F(1, 63) = .043, p = .84$ . One possibility is that the peculiarity of the indirect reach in the absence of the barrier was amplified when presented after a direct test event. However, this interpretation remains speculative.

*Continuous plots of fixations to the Ball AOI during the test phase.* To further illustrate the condition by age group interaction in the time at which participants first



fixated the ball during the test events, cumulative plots of the onset of participants' fixation to the Ball AOI during the Reach segment were created. In Figure 13, the cumulative proportion of trials on which participants looked at the Ball AOI was plotted by familiarization condition for each age group at each time point (every 20 or 16.7 ms, infants and undergraduates, respectively). Looking to the direct- and indirect-reach test events was plotted separately. Error bars represent standard error over participants.

As is clearly demonstrated by the fully overlapping curves in plots (b) and (c) of Figure 13, the gaze patterns of 10-month-olds and undergraduates were not differentiated by condition for either test event: 10-month-olds and undergraduates shifted their attention to the ball in the test events in the same manner regardless of whether they had previously been familiarized with a successful- or failed-reaching event. Moreover, at the time at which the actor's hand was 2 visual degrees away from the Ball AOI (2270 ms), participants had fixated the ball at equal proportions across conditions. Thus, both 10-month-olds and undergraduates interpreted the test events as goal-directed and predicted their outcome regardless of whether they had previously seen repeated successful or failed attempts.

This was not the case for 8-month-olds. As Figure 13(a) shows, 8-month-olds who had previously been familiarized with a successful-reaching event produced anticipatory looks at considerably higher levels during the test events than did those who had previously been familiarized with a failed-reaching event. This difference was apparent for both types of test events, but was even more pronounced for the indirect-reach events. Results are consistent with the view that 8-month-olds familiarized to the repeated failed attempt did not view even the successful grasps during the test events as directed toward the ball.

***Summary: Anticipatory looking and latency to the ball during the test phase.***

Overall, anticipatory looking and latency analyses during the test events demonstrated significant differences in how 8-month-olds, 10-month-olds, and undergraduates processed new reaching events after familiarization with a successful- or failed-reaching action. After watching the actor repeatedly grasp the ball successfully, participants of all ages continued to produce anticipatory looks to the ball in the new context where the barrier was absent. This was true both when the actor reached for the ball in a straight

path (direct-reach event) and when he reached for the ball in an arcing path (indirect-reach event). These results confirm that 8-month-olds, 10-month-olds, and undergraduates familiarized with a successful action during the familiarization phase recognized the direct and indirect actions during the test phase as goal-directed. In addition, results show that, after watching the actor repeatedly fail to grasp the ball, 10-month-olds and undergraduates also produced anticipatory looks to the ball during the test events. Indeed, anticipatory looks to the test events did not differ whether 10-month-olds and undergraduates were familiarized with the successful- or the failed-reaching event. These data suggest that, despite having learned that the actor will not retrieve the ball after multiple instances of watching him fail, when 10-month-olds and undergraduates saw the actor in a new context, they appropriately updated their expectations and again predicted that his behavior would be goal-directed.

Eight-month-olds, on the other hand, showed a different pattern of results. As in the familiarization phase, 8-month-olds in the failed-reaching condition did not show evidence that they interpreted the direct- and indirect-reach events as goal-directed. This was the case despite the fact that the test events showed successful outcomes. Thus, results indicate that 8-month-olds familiarized to a failed-reaching event did not revise their expectations about the actor's reaching actions based on reaching success in the new context of the test events. This finding may suggest that 8-month-olds encountered difficulty revising their implicit interpretation about the actor and his behavior in the failed-reaching condition.

Finally, slight differences in participants' latency of looking to the direct- versus indirect-reach events provide tentative evidence that participants were confused by or took longer to process the arcing trajectory of movement (in the absence of the barrier) in the indirect-reach event. This finding offers some explanation for the looking time differences to the direct- and indirect-reach events shown in Study 1.

### ***Duration of looking to the Ball, Head Space, and Reach Space AOIs during the test phase***

Given the focal findings concerning the ball (i.e., the goal object), a second key question concerns how participants distributed their attention among the other key components of the test events—the actor's face and the trajectory of the reaching action,

as well as the goal-object. Participants' relative attention to these AOIs was examined separately during the Reach, Grasp, and Freeze segments. These analyses were motivated by two key goals. The first was to confirm that participants of all ages (even the youngest infants) were following the flow of the test events appropriately by shifting their attention among the various AOIs. The second was to further explain global looking time differences between the direct- and indirect-reach test events observed in Study 1 by examining differences in participants' relative attention to the actor's face, the trajectory of the reaching action, and the goal object during these test events. I predicted that participants who were puzzled by the arcing reach in the absence of the barrier would look longer at the actor's face in search of explanatory information, particularly during the Freeze segment when the actor remained motionless with the ball in his hand.

**Reach segment.** First, the proportion of time participants spent looking within each of the three key AOIs during the period of time before the actor grasped the ball (the Reach segment; 0 to 2270 ms) was analyzed. In order to include both types of test events in the same analysis, a Composite Reach Space AOI was created by combining the Straight Reach Space and the Arcing Reach Space AOIs. An ANOVA was performed with test type (direct-reach, indirect-reach) and AOI (Ball, Head Space, Composite Reach Space) as within-subject factors and age group (8-month-olds, 10-month-olds, undergraduates), familiarization condition (successful-reaching, failed-reaching), gender (male, female), and test order (direct-indirect, indirect-direct) as between-subjects factors. Only effects and interactions related to AOI or test type are reported. Results revealed a main effect of AOI,  $F(2, 128) = 77.56, p < .001, \eta_p^2 = .55$ , significant two-way interactions of AOI by age group,  $F(4, 128) = 5.77, p < .001, \eta_p^2 = .15$ , and AOI by test type,  $F(2, 128) = 27.16, p < .001, \eta_p^2 = .30$ , and a three-way interaction of AOI by test type by age group,  $F(4, 128) = 2.50, p = .049, \eta_p^2 = .07$ .

As in the familiarization trials, participants spent the majority of time looking at the Head Space AOI ( $M = .40$ ) followed by the Composite Reach Space ( $M = .27$ ) and, finally, the Ball ( $M = .11$ ) AOIs. This effect was observed across age groups; however, the specific proportion of looking to each of the AOIs varied somewhat by age group. For example, there was a significant effect of age group in looking to the Ball AOI,  $F(2, 64) = 3.16, p = .049, \eta_p^2 = .090$ : 10-month-olds and undergraduates showed greater

looking to the Ball AOI ( $M_s = .13$  and  $.13$ , respectively) than did 8-month-olds ( $M = .076$ ), suggesting that older participants' interpretations of the test events were largely more centered on the ball than were those of younger participants. In addition, there was a linear effect of age group in attention to the Head Space AOI,  $F(2, 64) = 6.05$ ,  $p = .004$ ,  $\eta_p^2 = .16$ , with 8-month-olds showing the greatest proportion of looking to the actor's face ( $M = .47$ ), followed by 10-month-olds ( $M = .41$ ) and then undergraduates ( $M = .32$ ). These results indicate that, as in the familiarization phase, the actor's face and head were especially attention-getting for younger infants. Finally, there was a significant effect of age group in the proportion of looking to the Composite Reach Space AOI,  $F(2, 64) = 4.94$ ,  $p = .010$ ,  $\eta_p^2 = .13$ , showing that undergraduates looked longer at the Composite Reach Space AOI ( $M = .32$ ) than did 8- and 10-month-olds ( $M_s = .24$  and  $.24$ , respectively). Overall, patterns in attention during the Reach segment reveal modest age differences in attention to the three key AOIs. No major illuminating differences were observed.

Results also revealed effects of test type in how participants distributed their attention among the AOIs. As predicted, participants looked longer at the actor's face as it moved through the Head Space AOI during the indirect- than during the direct-reach event,  $F(2, 64) = 30.40$ ,  $p < .001$ ,  $\eta_p^2 = .32$  ( $M_s = .46$  and  $.34$ , respectively). Moreover, they looked longer at the Composite Reach Space AOI during the direct-reach than during the indirect-reach event,  $F(2, 64) = 33.71$ ,  $p < .001$ ,  $\eta_p^2 = .35$  ( $M_s = .32$  and  $.22$ , respectively). Longer looking to the actor's face in the indirect-reach test event may indicate that participants were puzzled by the arcing reach in the absence of the barrier and, thus, looked to the actor's face in search of more information. This confusion likely did not occur during the direct-reach because the path of this reach is rational and efficient in the absence of the barrier. This overall pattern of results was generally consistent across age groups and familiarization conditions.

**Grasp segment.** Next, to evaluate patterns of attention when the direct- and indirect-reach events made contact with the ball, analyses were conducted examining attention to the key components of the test events during the Grasp segment (2270-4810 ms). The proportion of time participants spent looking within each of key AOIs was entered into an ANOVA with test type (direct-reach, indirect-reach) and AOI (Ball, Head

Space, Composite Reach Space) as within-subject factors and age group (8-month-olds, 10-month-olds, undergraduates), familiarization condition (successful-reaching, failed reaching), gender (male, female), and test order (direct-indirect, indirect-direct) as between-subjects factors. Only effects and interactions related to AOI or test type are reported. Results revealed a significant main effect of AOI,  $F(2, 124) = 67.76, p < .001, \eta_p^2 = .52$ , as well as a two-way interaction of AOI by age group,  $F(4, 124) = 2.57, p = .041, \eta_p^2 = .077$ , and a three-way interaction of AOI by age group by condition,  $F(4, 130) = 3.39, p = .011, \eta_p^2 = .099$ . No significant effects of test type were observed.

As expected, during the Grasp segment of the test events, participants spent the majority of time looking at the Ball AOI ( $M = .44$ ) followed by the Composite Reach Space ( $M = .21$ ) and, finally, the Head Space ( $M = .053$ ) AOIs. However, this effect varied by age group and condition. In particular, 8-month-olds who were previously familiarized with the failed-reaching action spent significantly less time looking at the Ball AOI during the Grasp segment of the test events than did infants at the same age who saw the successful-reaching event,  $F(2, 62) = 5.59, p = .006, \eta_p^2 = .15$  ( $M_s = .47$  and  $.23$  for the successful- and failed-reaching conditions, respectively). This finding was unexpected since the test events were identical across familiarization conditions. That is, despite differences in the actor's reaches during the familiarization events, in both conditions the actor's hand enters the Ball AOI and grasps the ball during the test events. That 8-month-olds previously familiarized with the failed-reaching action showed this level of inattention to the ball (even during the Grasp segment) suggests that their interpretation of the actor's reaching (based on familiarization experience) includes very little role for the goal-object.

**Freeze segment.** Finally, analyses were conducted examining attention to the key components of the test events when the reaching actions were complete—during the Freeze segment. An ANOVA was performed with test type (direct-reach, indirect-reach) and AOI (Ball-Hand, Face) as within-subject factors, and age group (8-month-olds, 10-month-olds, undergraduates), familiarization condition (successful-reaching, failed reaching), and gender as between-subjects factors. Only effects and interactions related to AOI or test type are reported. Results revealed a significant interaction of AOI by test type,  $F(1, 66) = 4.20, p = .044, \eta_p^2 = .060$ , that is best explain in light of a marginal three-

way interaction of AOI by test type by test order,  $F(2, 66) = 2.45, p = .053, \eta_p^2 = .055$ . Overall, participants distributed their attention equally between the Ball-Hand and Face AOIs in the Freeze segment following both the direct- and the indirect-reach events ( $p$  values  $> .18$ ). Nevertheless, there was a significant effect of test type in the proportion of time participants spent looking at the Face AOI. Results showed longer looking to the Face AOI in the Freeze segment following the direct-reach ( $M = .35$ ) than in the Freeze segment following the indirect-reach event ( $M = .30$ ),  $F(1, 66) = 5.67, p = .020, \eta_p^2 = .079$ . This result was unexpected based on both the prediction that attention to the actor's face would be heightened after performance of a surprising reach (indirect-reach event) and data from the Reach segment showing increased attention to the actor's face during the Reach segments of the indirect-reach events. It is important to note, however, that this effect was only observed in participants who saw the direct-reach event before they saw the indirect-reach events; participants in the indirect-direct test order did not show this difference. Therefore, no strong conclusions should be drawn.

***Continuous plots of looking to the Ball, Head Space, and Reach Space AOIs during the test phase.*** Finally, to shed further light on how participants shifted their attention between the key AOIs as the direct- and indirect-reach events unfolded over time, the noncumulative proportion of trials on which participants looked at each AOI (Head Space, Composite Reach Space, Ball) during the Reach and Grasp segments was plotted separately for each age group, familiarization condition, and test type at each timestamp (Figures 14 and 15).

Consider, first, the overall picture across age groups and conditions. These plots indicate that, as in the familiarization phase, participants of all ages were following the flow of the test events as would be expected. Participants shifted their attention from the actor's face, to the space in which the actor's arm moved, to the ball. Note that compared to the plots from the familiarization phase, attention to the Head Space AOI during the test events was diminished. This is likely due to the fact that the test events did include the 1000 ms segment in which the actor peered over the barrier to focus on his goal prior to initiating his reach.

The plots in Figures 14 and 15 also help to illustrate the proportion of looking data reported in the previous analyses. First, the main effect of AOI during the Reach

segment (0-2270 ms) can be seen. The Head Space AOI was again the dominant focus of attention, followed by the Composite Reach Space and finally the Ball AOIs. Second, these plots also illustrate the interaction of AOI by age group during the Reach segment. The linear effect of age group in attention to the Head Space AOI can be seen: 8-month-olds showed the greatest attention to the Head Space AOI, followed by 10-month-olds and undergraduates, suggesting that the actor's face and head were more attention-getting for younger participants. Moreover, age group differences in attention to the Ball AOI can also be seen. Ten-month-olds and undergraduates showed greater looking to the Ball AOI than did 8-month-olds, although this effect was apparently driven primarily by 8-month-olds who were previously familiarized with the failed reaching action.

The plots in Figures 14 and 15 also illustrate the interaction of AOI by test type during the Reach segment. During the indirect-reach event, participants looked more at the Head Space AOI and less at the Composite Reach Space AOI than during the direct-reach event. These differences may indicate that participants were confused by the arcing test reach and, thus, looked to the actor's face for an explanation. However, these differences should also be considered in light of the way in which the Head Space and Reach Space AOIs were defined. As was the case for the familiarization events, because of the arcing trajectory of the reach, the actor's arm moved inside the Head Space AOI during the indirect-reach test event. This was not the case for the direct-reach. Because the actor reached directly (in a straight line) toward the ball, in the direct-reach test event his arm never crossed into the Head Space AOI. Thus, the test type differences observed in participants' attention to the actor's face versus his reach must be interpreted cautiously. The current Head Space AOI may provide an inflated estimate of participants' attention to the actor's face during the indirect-reach event.

Finally, the plots in Figures 14 and 15 also demonstrate the effects of age group and condition on looking during the Grasp segment (2271-4810 ms). As would be expected, the Ball AOI was the dominant AOI during the Grasp segment. However, this effect varied by age group and condition. In particular, the plots in Figures 14 and 15 show that 8-month-olds who were previously familiarized with the failed reaching action devoted considerably less attention to the Ball AOI during the Grasp segment of the test events than did older infants and undergraduates who saw the same familiarization event,

as well as 8-month-olds who watched the successful familiarization event. This finding confirms that the interpretation of the reaching action held by 8-month-olds who were familiarized with the failed-reaching action included little role for the ball. Even when his hand entered the Ball AOI and grasped the ball, 8-month-olds who had received previous evidence of repeated failures paid little attention to the ball.

***Summary: Looking to the Ball, Head Space, and Reach Space AOIs during the test phase.*** Overall, the proportion analyses together with the continuous plots of looking to the Ball, Head Space, and Composite Reach Space AOIs help to clarify how 8-month-olds, 10-month-olds, and undergraduates familiarized with successful- or failed-reaching events shifted their attention among the key AOIs in the direct- and indirect-test events. Three general conclusions can be drawn. First, as with the familiarization events, in the new context of the test events, participants of all ages followed the flow of the direct- and indirect-reach events appropriately by shifting their attention from the actor, to his reach, to the ball.

Second, 8-month-olds previously familiarized with the failed-reaching event distinguished themselves from all other participants (i.e., 8-month-olds in the successful-reaching condition, 10-month-olds and undergraduates in both conditions) by showing considerably less attention to the Ball AOI—even when the actor’s hand entered the AOI and grasped the ball. Although this finding is consistent with the hypothesis that 8-month-olds who previously saw the actor fail repeatedly did not view his actions as goal-directed, this result is also surprising as it indicates that 8-month-olds were unable to revise their interpretation in the new environmental context (i.e., no barrier) and in the presence of new evidence (i.e., successful outcomes).

Finally, despite significant differences in global measures of infants’ looking to the direct- and indirect-reach test events in Study 1, only subtle differences were observed in infants’ and undergraduates’ attention to the actor’s face, his reach, and the ball as the direct- and indirect-reach test events unfolded over time. Namely, participants looked longer at the actor’s face during the Reach segment of the indirect-reach event and during the Freeze segment of the direct-reach event. Although these effects may reflect differences in participants’ processing of the two kinds of test events, caution must be taken when interpreting these differences for two reasons. First, these effects emerged in



the direct-indirect test order only, suggesting that they may not be very robust. Second, due to the temporary inclusion of the actor's hand in the Head Space AOI (for the indirect-reach event only), estimates of attention to the Reach Space and Head Space AOIs may not be fully accurate.

### ***Evaluating Relations between Performance in the Experimental Task and on the Parent-Report Measure***

A secondary goal of the current study was to explore how variability in understanding intention as revealed in the experimental task may be related to variability in the behaviors and abilities of infants outside of the laboratory. To explore this goal, the results of the parent questionnaire were examined. Infants' self-locomotion abilities, their ability to produce means-end behaviors, and their joint attention skills were used to predict their ability to process the intentional actions in the experimental task.

#### **Parent Questionnaire Sub-Scores**

First, self-locomotion, means-end behavior, and joint attention sub-scores on the parent questionnaire were computed as described below. Note that parent questionnaire data were not available for 9 of the participants tested in the experimental task (6 8-month-olds; 3 10-month-olds) and thus those participants were not included in the subsequent analyses.

#### ***Self-locomotion scores***

Self-locomotion scores were calculated by summing parents' responses to three gross motor items ("Does your child crawl?"; "Does your child walk with support?"; "Does your child walk independently?"). The item "Does your child pull him/herself to a standing position?" was excluded from this score because it did not specifically address locomotive ability. For each item, infants were given a score of 0 (not yet), 1 (sometimes), or 2 (often). Thus, total self-locomotion scores ranged from 0, for infants who were not yet crawling, to 6, for infants who were walking independently ( $M = 2.78$ ,  $SD = 1.50$ ). Independent samples t-tests revealed that 10-month-olds received higher self-locomotion scores ( $M = 3.58$ ) than did 8-month-olds ( $M = 1.91$ ),  $t(44) = 4.72$ ,  $p < .001$ . There were no differences in the self-locomotion abilities of infants assigned to the successful- and failed-reaching conditions,  $t(44) = 0.90$ ,  $p = .37$ .

### ***Means-end behavior scores***

Two items on the parent questionnaire were designed to assess infants' ability to produce means-end behaviors—"Does your child search for objects that are covered up or partially covered up (e.g., lift a cloth to retrieve a hidden object)?" and "Does your child reach for objects that are out of reach?" Because all parents reported that their child "reaches for objects that are out of reach", the second item was dropped from further analyses and only the first item was used as a measure of means-end ability. Scores for this item ranged from 0 (not yet) to 2 (often;  $M = 1.51$ ,  $SD = 0.66$ ). Ten-month-olds received higher scores ( $M = 1.72$ ) than did 8-month-olds ( $M = 1.27$ ),  $t(45) = 2.46$ ,  $p = .018$ , and there were no differences in the means-end abilities of infants assigned to the successful- and failed-reaching conditions,  $t(45) = 0.55$ ,  $p = .59$ .

### ***Joint attention scores***

A factor analysis was conducted on the joint attention items to evaluate patterns among the 12 items and to assess whether they could be best explained in terms of a smaller number of variables. Questionnaire data from 3 participants who were dropped from the experimental task but whose parents responded to the questionnaire were included in this analysis. Additionally, to supplement our sample, data from an additional 62 infants between the ages of 7.33 and 10.87 months who participated in a different experimental task but whose parents also responded to the parent-questionnaire were also included in the factor analysis. Altogether, the factor analysis was conducted on data from a total of 112 participants (51 males, 61 females;  $M = 9.15$  months,  $SD = 1.08$ ).

Principle components analysis was used because the primary purpose of the analysis was to identify and compute composite scores for the factors differentiating these items. The initial eigenvalues showed that the first factor explained 27.4% of the variance, the second factor 14.6% of the variance, and a third factor 9.8% of the variance. The subsequent factors had eigenvalues of less than one with each factor explaining less than 8% of the variance. The two- and three-factor solutions were examined, using a varimax rotation of the factor loading matrix. The two-factor solution, which explained 37.5% of the variance, was preferred because of the 'leveling off' of eigenvalues on the scree plot after two factors and because of the difficulty of interpreting the third factor.

One item, “Does your child respond to his/her name?” was eliminated because it did not contribute to a simple factor structure and failed to meet a minimum criteria of having a primary factor loading of .4 or above. A principle-components factor analysis of the remaining 11 items, using varimax rotation was conducted, with the two factors explaining 44.0% of the variance. All items had primary loadings over .4. The factor loadings and reliabilities for the final solution are presented in Table 1.

As is clear from Table 1, what differentiates these factors is whether the behavior they assess is active or responsive (i.e., a way to initiate or respond to joint attention). The 6 items that loaded onto Factor 1 all address active behaviors produced by infants, in most cases to direct the attention of others in certain ways (e.g., pointing to ask for something, trying to attract others’ attention to his/her own activity). The 5 items that loaded onto Factor 2 all assess receptive behaviors produced by infants to follow the attention of others or use others as sources of information (e.g., following gaze, checking others’ reaction when faced with something unfamiliar). These factors correspond to two distinct behavioral dimensions of joint attention that have been used and identified by others in the field (e.g., Carpenter et al., 1998; Mundy et al., 2007). Here I adopt the nomenclature suggested by Seibert et al. (1982) that is currently widely used in the research literature (see Mundy et al., 2007). The first factor, *initiating-joint-attention* refers to the ability to use direction of gaze and gestures to direct the attention of others to spontaneously share experiences. The second factor, *responding-to-joint-attention* refers to the ability to follow the direction of gaze and gestures of others.

Composite scores for the initiating- and responding-to-joint-attention factors were created for participants who participated in the experimental task by calculating the average score of the items that loaded on each factor. Possible scores for each factor ranged from 0 to 2 (initiating-joint-attention:  $\alpha = .69$ ;  $M = 1.00$ ,  $SD = 0.44$ ; responding-to-joint-attention:  $\alpha = .49$ ,  $M = 1.45$ ,  $SD = 0.32$ ). Only scores on the initiating-joint-attention factor varied by age group,  $t(45) = 3.58$ ,  $p = .001$ ,  $M_s = 0.78$  and  $1.20$  for 8-month-olds and 10-month-olds, respectively. Most likely due to near ceiling responses, there was no effect of age group for scores on the responding-to-joint-attention factor,  $t(43) = 1.05$ ,  $p = .30$ . Note that this is consistent with research showing that the behaviors included in the responding-to-joint-attention factor emerge at younger ages than those in

the initiating-joint-attention factor (Carpenter et al., 1998). In addition, there were no differences between the infants assigned to the successful- and failed-reaching conditions on either the initiating-joint-attention factor,  $t(45) = 0.58$ ,  $p = .57$ , or the responding-to-joint-attention factor,  $t(43) = 0.30$ ,  $p = .77$ .

### **Intercorrelations between Parent-Report Measures**

First, intercorrelations between the different parent-report measures were examined for infants who participated in the eye-tracking task. As indicated in Table 2, initiating-joint-attention, self-locomotion, and means-end ability were each positively correlated with age. Self-locomotive abilities were also positively related to initiating-joint-attention. Finally, there was a significant, positive association between responding-to-joint-attention and means-end abilities. No other significant associations emerged.

Partial correlations were also conducted to examine the associations between the different behavioral measures when controlling for age. Findings indicated that the relations between self-locomotive abilities and initiating-joint-attention,  $r(41) = .32$ ,  $p = .037$ , and between responding-to-joint-attention and means-end abilities,  $r(41) = .34$ ,  $p = .028$ , each remained significantly related when controlling for age.

### **Correlations between Intention Understanding and Parent-Report Measures**

To examine relations between intention understanding and the continuous measures tapping infants' self-locomotive, means-end, and joint attention abilities, bivariate correlations were conducted using infants' latency of looking to the ball on Triad 1 as the outcome variable. The latency measure was selected because it provided a continuous outcome. In addition, the first triad was selected because it showed the most pronounced effects of age group and condition. Separate analyses were run for the successful- and failed-reaching conditions since these conditions yielded different patterns of results in the latency analyses and were hypothesized to show different associations with the infant behavior measures.

Consider first the successful-reaching condition. As shown in Table 3, no associations emerged between infants' social and motor abilities and their latency to look at the ball in Triad 1. A different pattern of results emerged for the failed-reaching condition. Results showed that greater self-locomotive abilities and more frequent

attempts to initiate joint attention were each significantly correlated with faster latency to look at the ball in the failed-reaching condition. No associations emerged for means-end ability or the responding-to-joint-attention factor.

Because the infant measures were generally shown to vary by age group, partial correlations were also conducted examining the associations between the behavioral measures and the latency to look to the ball in Triad 1 when controlling for age. Findings indicated that self-locomotive abilities and the initiating-joint-attention factor each remained significantly correlated with faster latency to look at the ball in the failed reaching condition (see Table 4). No other associations emerged.

A similar pattern of results was observed using infants' average latency of looking to the ball during the test events as the outcome variable (see Tables 3). Bivariate correlations revealed that self-locomotive abilities and the initiating-joint-attention factor were each significantly correlated with faster latency to look at the ball after familiarization with the failed-reaching event. Partial correlations controlling for age confirmed this result for self-locomotive abilities, but not for the initiating-joint-attention factor (see Table 4). No other associations emerged.

### **Summary**

In sum, the analyses examining the relation between variability in intention understanding as revealed in the experimental task and variability in the behaviors and abilities of infants outside of the laboratory support two broad conclusions. First these results are consistent with the hypothesis that the development of intention understanding is intimately linked with other important developmental achievements. Specifically, data indicate that infants who have more advanced motor abilities and are more proficient at initiating-joint-attention also show quicker recognition of the goal of a failed intentional action. Note that due to the concurrent correlational nature of these data, however, the causal direction of these relations cannot be known. Second, the fact that these behavioral abilities were found to be predictive of latency to look to the ball only in the failed-reaching condition helps to validate two basic premises of the current studies: that reasoning about a failed action requires a different understanding of human behavior than does reasoning about a successful goal-directed action, and that failed actions provide a better, more diagnostic test of infants' ability to understand intention.

## Discussion

Study 2 was designed to address two goals related to the development of an understanding of intention. The first goal was to better characterize similarities and differences in 8- and 10-month-olds' processing of both successful and failed goal-directed actions in order to gain insight into *what* changes between 8- and 10-months and, ultimately, *how* those changes occur. An important but secondary goal was to explore how variability in understanding intention as revealed in infants' reasoning about successful and failed goal-directed actions may be related to variability in the development of other important social and motor abilities. The results of Study 2 provide new insights into infants' emerging ability to predict the goal of a failed goal-directed action and the relation between this ability and developments in social and motor behavior.

### **Infants' Processing of Intentional Actions in Real Time**

The anticipatory looking and latency data presented here converge to suggest that by 10 months of age, infants can predict the outcome of a goal-directed action, even when the action is unsuccessful and the actor fails to achieve his goal. These data add to the recent body of evidence showing that infants in the first year of life perceive failed actions as guided by intentions that are not manifested in action (Behne et al., 2005; Brandone & Wellman, 2009; Daum et al., 2008; Hamlin et al., 2009a, 2009b; Legerstee & Markova, 2008). Importantly, the current study is the first to provide evidence of failed action understanding using a predictive looking task. This method provides the most comprehensive and compelling evidence of failed action understanding by demonstrating not only that 10-month-olds can evaluate failed actions *retrospectively* (as indicated by previous research and Study 1), but also that they can predict the goal of another's action *prospectively* after observing a failed attempt (see Gredebäck & Melinder, 2010 for further discussion of the difference between retrospective and prospective action analysis).

Younger infants, however, did not show this ability. Eight-month-olds in the current study showed predictive looks to the outcome of the successful-reaching action only. When the action was unsuccessful and the actor failed to achieve his goal, 8-month-olds instead tracked the actor's failed reach in a more reactive manner—looking

much later and sometimes not at all at the goal of the failed reach. These findings confirm and extend the looking time data observed in Study 1. Recall that Study 1 used infants' global looking times to two contrasting test events to assess their retrospective understanding of directly comparable successful and failed goal-directed actions. As in the current study, results from Study 1 revealed that 8-month-olds demonstrated an understanding of the successful-reaching action but not an equivalent understanding of the failed-reaching action. Taken together, the looking time and anticipatory looking data from Studies 1 and 2 provide firm evidence of a developmental trajectory whereby understanding successful goal-directed actions precedes understanding failed goal-directed actions.

Data from the test phase of the current experiment—in which the same actor again reached for the same ball in a somewhat different context (i.e., where the barrier no longer stood between him and his goal)—further support these developmental differences. Eight-month-olds and 10-month-olds familiarized with the failed reaching action showed dramatically different expectations for how the actor would behave in the new context. Despite never having seen him grasp the ball in the original context, in this new context, 10-month-olds again showed predictive looks to the ball; 8-month-olds, on the other hand, tracked the actor's reach in a more reactive manner—looking to the ball much later and sometimes not at all. The fact that 8-month-olds did not revise their expectations after seeing the actor successfully grasp the ball during the test events raises important additional questions about what support infants need to interpret failed actions. Nevertheless, these data provide still more compelling evidence that 8-month-olds do not view failed actions as goal-directed.

A key question arising from these data becomes what explains this developmental difference in processing successful and failed goal-directed actions. The current study provided one way to explore this question by examining whether there were age-related differences in how participants distributed their attention among the key components of the successful- and failed-reaching events—the actor's face, the trajectory of the reaching action, and the goal-object. Results showed that even by 8 months of age participants followed the flow of the reaching events appropriately by shifting their attention from the actor, to his reach, to the ball. This overall pattern of looking was remarkably consistent

across age groups and across successful- and failed-reaching conditions. Thus, results revealed that 8-month-olds in the failed-reaching condition showed a pattern of looking to the key AOIs that was *not* qualitatively different from that of older infants or 8-month-olds in the successful-reaching condition. Beyond subtle differences in attention to the actor's face and reach, the only notable difference between the other participants and 8-month-olds in the failed-reaching condition, was that 8-month-olds in the failed-reaching condition showed less overall looking to the ball when the context changed (i.e., during the test events). Overall, these findings importantly demonstrate that developmental differences in how 8-month-olds and 10-month-olds interpret failed goal-directed actions cannot be explained by global differences in how they distributed their attention among the various components of human action. Instead, these age differences are more likely driven by differences in how 8-month-olds and 10-month-olds interpret and make sense of the information they are taking in.

To pursue this interpretative difference further, consider the essential difference between successful and failed goal-directed actions. In the case of a successful action, the actor's goal is made apparent in the action's achieved physical outcome (e.g., successfully grasping the ball). In the case of a failed action, however, the actor's goal is unrealized and, thus, there is no visible achievement of the goal-object to instantiate the actor's goal. Developmental differences in infants' ability to interpret successful and failed goal-directed actions likely rest on this distinction. For example, the fact that 8-month-olds in Studies 1 and 2 demonstrated an understanding of the successful-reaching action (and it alone) suggests that at this early age, infants needed outcome information to determine the goal of the action. Only after seeing the actor successfully grasp and retrieve the ball were they able to interpret his reach as goal-directed and, thus, produce predictive looks to the ball on subsequent trials. When 8-month-olds saw the actor reach for but fail to grasp or make contact with the ball, they simply tracked the trajectory of his arm. This pattern of results is consistent with the view that infants' initial understandings of human action are somewhat superficial in nature: they capture certain regularities of action (e.g., that actions are directed toward objects and are rational and efficient; Csibra et al., 1999; Gergely et al., 1995; Phillips & Wellman, 2005; Woodward, 1998), but not deeper internal states.



In contrast, older infants' understandings go beyond this surface level. The fact that 10-month-olds in Studies 1 and 2 demonstrated an understanding of both the successful- and the failed-reaching actions suggests that, by this age, outcome information was not required for infants to identify the actor's goal. They were able to interpret his reach as goal-directed even without seeing the actor make contact with the ball. An intriguing possibility, and the interpretation that I favor, is that 10-month-olds are able to infer the goal of a failed action because they have begun to view human behavior not only as goal-directed, but also as intentional—motivated by subjective, internal states<sup>4</sup>.

Note that these conclusions rest on two important features of eye-tracking methodology that are not available in other infant methods (e.g., visual habituation). First is the ability to measure anticipatory processing, revealing how infants predictively recognize and anticipate an action's goal. Second, is the ability to examine the microstructure of looking behavior to reveal infants' shifting patterns of attention as stimulus events unfold over time.

Finally, it is important to note that the interpretation offered here assumes that what drives goal anticipation is an understanding of the goal of the observed action. Although this perspective is well supported (e.g., Csibra, 2007; Eshuis, Coventry, & Vulchanova, 2009), it is not the only view. Gredebäck and colleagues (2009) suggest that action understanding and, specifically, goal anticipation is mediated by a process of direct matching in which an observed action is mapped onto a motor representation of that action (see also Rizzolatti et al., 2001). On this view, an observer's own action capabilities, not the observer's understanding of the other actor's goal, mediate goal anticipation during action observation. Support for this position comes from research showing that, before infants reach the age at which they start to place objects inside containers, they interpret these actions in others in a reactive manner (Falck-Ytter et al., 2006) and that toddlers who solve a manual puzzle task efficiently are more proficient at anticipating the goal of similar actions performed by others (Gredebäck & Kochukhova,

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<sup>4</sup> Note that it is possible that 8-month-olds also have some capacity for intention understanding that they are simply not demonstrating in these tasks. However, because 8-month-olds showed clear understanding in the successful-reaching condition (which was directly comparable to the failed-reaching condition and involved equivalent task demands), this remains unlikely.

2010). However, a direct matching explanation cannot easily explain the pattern of results observed in the current study. In particular, on a direct matching hypothesis, there is no reason why 8-month-olds' performance should differ across the successful- and failed-reaching conditions, because both conditions used a simple action (i.e., reaching) that infants can perform with ease by 8 months of age (e.g., Thelen et al., 1993). Thus, although it is very likely that infants' own first-person experience engaging in goal-directed actions contributed to their understanding of the actor's goal in the current study (and to their understanding of intentional action more broadly, e.g., Woodward, 2009), a direct matching explanation which considers infants' action capabilities alone cannot explain the present pattern of findings.

In sum, the data presented here provide evidence for an early intentional understanding of human behavior that emerges between the ages of 8 and 10 months. Moreover, consistent with the theoretical proposals of Gergely and Csibra (2003), Wellman and Phillips (2001), and Woodward (1998), these data show that this early intentional understanding of action appears later than, and potentially builds upon an earlier understanding that is both shallower and more concrete.

### **The Relation between Intention Understanding and Social and Motor Development in Infancy**

A second contribution of the current study is its documentation of the relation between intention understanding and other emerging motor and social abilities. This study is one of the first to establish a clear relationship between experiences occurring in infants' daily lives and goal anticipation (for other examples, see Gredebäck & Melinder, 2009; Gredebäck & Kochukhova, 2010). Specifically, data showed that two of the parent-report measures—one involving joint attention abilities and one involving self-locomotion—were associated with participants' latency of looking to the ball in the failed-reaching condition of the experimental task. Latency data arguably provide a particularly important and revealing measure of infant intention understanding by capturing (in a quantitative way) infants' abilities to predictively recognize and anticipate a person's non-overt goal states.

Consider, first, the joint attention factors. It has long been assumed that social behaviors in which infants follow, direct, or share others' attention are all behavioral

manifestations of an underlying understanding of people as intentional agents. The argument goes that when infants follow others' gaze shifts, point to objects, and engage in shared attention, their actions directly reflect a basic appreciation of others' intentions (e.g., Bretherton, 1991; Carpenter et al., 1998; Tomasello, 1999). Although individual differences in these abilities among infants have been shown to be related to variability on a number of measures in subsequent language and cognitive development (e.g., Adamson et al., 2004; Carpenter et al., 1998; Delgado et al., 2002; Mundy & Gomes, 1998; Nichols, Fox, & Mundy, 2005; Smith & Ulvund, 2003; Tomasello & Todd, 1983), few studies have directly tested the association between these joint attention abilities and an understanding of intention as assessed in experimental studies and, in particular, in studies that rely on careful analysis of infants' attention to intentional action.

Two notable exceptions come from the research of Woodward and colleagues. For example, Brune and Woodward (2005) 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 (2005) 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 10-minute free play period) was systematically related to infants' understanding of the actor-object relation in a gaze event (in a habituation task). Woodward and colleagues' data provided the first (and possibly only) evidence that infants' emerging social understanding correlates with at least a limited set of social behaviors.

Results of the current study extend these results, demonstrating that variability in the extent to which infants use gestures and direction of gaze to guide the attention of others (the initiating-joint-attention factor) predicts their ability to interpret the goal of a failed action: Infants who were reported by their parents to initiate joint attention more frequently showed faster latency of looking to the goal of a failed-reaching action. This effect emerged even when controlling for age. Thus, data provide support for the hypothesis that joint-attention-initiating behaviors are intimately linked with an understanding of intention.

Notably, a different pattern of results emerged for the responding-to-joint-attention factor—the ability to follow the direction of gazes and gestures of others. Although these behaviors are also assumed to reflect an understanding of intentional relations (e.g., Bretherton, 1991; Tomasello, 1995) the current study showed otherwise. Brune and Woodward (2005) reported a similar finding. They found that infants' orienting responses were unrelated to their sensitivity to the intentional structure of gaze and pointing events in a habituation task. What explains this null result? First, consider methodological concerns with the responding-to-joint-attention factor. In the current study, scores on the items loading on this factor were consistently high and showed low variability. In addition, the alpha coefficient for this factor was .49, suggesting that the items loading on this factor have relatively low internal consistency, decreasing the likelihood of finding an association if one truly exists. A potentially related concern is that, because the items loading on the responding-to-joint-attention factor were less active in nature, they may have been more challenging for parents to assess. If this were the case, data from these items would be less accurate and the factor less sensitive. These limitations cannot be ruled out in the present study.

A more interesting theoretical explanation for the association between intention understanding and joint attention only for initiating-joint-attention and not responding-to-joint-attention is that these factors reflect distinct dimensions of joint attention that are differentially related to intention understanding. This possibility is supported by research showing that these two dimensions of joint attention display different patterns of age-related growth in infancy, have unique associations with subsequent development and reflect different underlying processes during infant development (Mundy et al., 2007). For example, neuropsychological research suggests that responding-to-joint-attention is associated with parietal activity and may be part of a relatively reflexive system of orienting to biologically meaningful stimuli that develops early in the first year of life (e.g., Mundy et al., 2000; D'Entremont et al., 1997; Rothbart, Posner, & Rosicky, 1994; Posner & Petersen, 1990). Along these lines, Moore and colleagues (Barresi & Moore, 1996; Corkum & Moore, 1995) have offered a lean view of responding-to-joint-attention behaviors such as gaze following that is far removed from any appreciation of the intentional properties of gaze. On this view, early in development, infants turn in the

direction of others' attention by tracking salient movement cues or because they have learned to do so through operant reinforcement. Not until later in development—beyond the age of the infants in the current study—do these behaviors become guided by intention understanding (for examples of more sophisticated gaze following that reflects intention understanding, see Brooks & Meltzoff, 2002, 2005; Meltzoff & Brooks, 2008; Moll & Tomasello, 2004).

Neuropsychological evidence suggests that initiating-joint-attention, on the other hand, is associated with activation of frontal brain areas (Henderson et al., 2002; Mundy et al., 2000; Mundy, 2003) and may be part of a more volitional attention system that develops later in infancy (e.g., Rothbart et al., 1994). On this view, the more purposeful use of behaviors such as eye contact or gestures to spontaneously initiate coordinated attention with a social partner in initiating-joint-attention may be more clearly intertwined with infants' understanding of intention.

An important question that arises from the observed association between intention understanding and initiating-joint-attention is the question of the direction of the relation. In particular, does joint attention develop after a foundational understanding of intention is in place and provide a behavioral manifestation of this understanding? Or, does an understanding of intention follow from the development of joint attention and perhaps increasing abilities at initiating-joint-attention promote an underlying understanding of intention that becomes manifest in the experimental task? Some have proposed that intention understanding is necessary for the development of joint attention in infancy (e.g., Tomasello, Carpenter, Call, Behne, & Moll, 2005). On this view, an understanding of others as intentional agents provides both the motivation to engage in joint attention and the foundation for joint attention interactions. Others, however, argue that practice with joint attention is a major contributor to rather than a product of the development of intention understanding (e.g. Corkum & Moore, 1995; Mundy & Newall, 2007). On this view, joint attention interactions provide the kinds of experiences necessary for infants to acquire a view of others as intentional agents. Although the current data cannot speak to the question of causation, they nevertheless provide some of the first support for the hypothesis that joint-attention-initiating behaviors and intention understanding are deeply related.

Beyond these joint attention behaviors, the current study is the first to show that infants with more advanced self-locomotive abilities demonstrate quicker recognition of the goal of a failed intentional action. How might self-locomotion be related to intention? Prior research has found that the onset of crawling marks an important developmental milestone that profoundly changes the way infants experience and interact with their world. Researchers argue that crawling represents more than just a motor milestone as learning to crawl is also associated with changes in infants' social and exploratory behaviors (e.g., Campos et al., 1997; Green, Gustafson, & West, 1980; Gustafson, 1984; see Campos et al., 2000 for a review). For example, Campos, Kermoian, and Zumbahlen (1992) found that parents of crawling infants reported their infants to be more affectionate towards their mother, more sensitive to maternal comings and goings, and more attentive to distal events than did parents of non-crawling infants. In addition, Campos et al. found that crawling onset also affected mother-infant interactions, with crawling infants spending more time in interactive play games and more time in distal communicative interactions with their mothers than non-crawling infants. Recent evidence has also shown that the onset of independent walking may be associated with additional changes in infants' social experiences. For example, Clearfield (in press) tracked infants longitudinally across the transition from crawling to walking. She observed significant changes in infants' interactions with their mothers and with objects in their environment as they learned to walk. Specifically, the transition to independent walking was associated with marked increases in the length of time infants spent interacting with their mothers and, intriguingly, producing directed gestures intended to guide their mother's attention to objects of interest. Preliminary support for this view also comes from the fact that self-locomotive abilities and the initiating-joint-attention factor were significantly correlated in the current study, even when controlling for the effects of age. Intriguingly, together these data tentatively suggest that self-locomotive abilities may contribute to an emerging understanding of intention by altering infants' experiences with those around them and inviting opportunities for joint attention interactions.

Lastly, consider the lack of an observed correlation between intention understanding and the crude measure of means-end action production that was used in the

current study. In a general sense, the ability to produce behaviors that involve the deliberate, planful execution of a sequence of steps to achieve a goal in situations where an obstacle prevents achieving that goal (e.g., removing a cover to search for a hidden object; Willatts, 1999) is an important developmental achievement that may well be an essential component of an understanding of the means-end action sequences of others. Although no studies (to my knowledge) have examined the relation between intention understanding and this broad ability to perform means-end behaviors, there is clear evidence that the ability to produce *specific* means-end action sequences is related to infants' perception of those behaviors in others. For example, Sommerville and Woodward (2005) showed that variability in infants' ability to produce planful actions such as pulling a cloth to get a toy on its far edge was significantly correlated with their looking-time responses to events in which an actor produced this same behavior. Infants who were well-organized in their own ability to pull a cloth to get a toy viewed the cloth pulling action of another person as directed toward the ultimate goal—the toy. In contrast, infants who were not able to perform this means-end action understood the cloth pulling action of the other person as directed toward the cloth. Sommerville and colleagues (in press) have also found that training to produce similar, unfamiliar means-end actions influenced whether infants understood these actions in others in terms of their means or their ultimate goal. These results provide firm evidence that specific means-end action abilities are related to intentional means-end action understanding. Thus, failure to find evidence of this association in the current study may very well be due to the imprecision of the measure used to assess means-end action production.

A key point to emphasize from these correlational analyses is that the associations observed between infants' social and motor behaviors and intention understanding as demonstrated by latency of looking to the ball in the experimental task emerged only in the failed-reaching condition. There were no significant correlations between any behaviors assessed on the parent questionnaire and latency of looking to the ball in the successful-reaching condition. The fact that these behaviors presumed to be related to the emergence of intention understanding in infancy were only found to be associated with failed-action understanding helps to validate three basic assertions of the current studies: (1) that reasoning about a failed goal-directed action requires a different understanding of

human behavior than does reasoning about a successful goal-directed action; (2) that failed actions provide a better, more diagnostic test of infants' ability to understand intention; and (3) that an intentional understanding of human behavior evidenced by failed action understanding emerges between the ages of 8 and 10 months.

Finally, it is important to note that, due to the correlational nature of these data, conclusions about the direction of causation in the observed associations are limited. For example, it is possible that the association between latency of looking to the ball in the failed-reaching event and measures of joint attention abilities and self-locomotion might be mediated by a third variable such as IQ, information-processing ability, or overall differences in participants' maturity. The fact that these relationships did not emerge in the successful-reaching condition argues against this possibility, as variability in these areas should also be associated with differences in processing successful actions. Nevertheless, future work should more carefully disentangle the associations observed here.

## **Conclusion**

Through the unique combination of fine-grained, real-time measures of event processing and parent-report data on infants' social and motor behaviors in the real world, the current study provides important insight into how an understanding of intention emerges during a transitional period of development in infancy. Between 8 and 10 months of age, infants develop the ability to predict the outcome of a goal-directed action—even when the action is unsuccessful and the actor fails to achieve his goal. Moreover, variability in performance on this task is related to both infants' ability to self-locomote and the extent to which they direct the attention of others and initiate shared experiences. The developmental picture emerging from these data is that, through joint-attentive social interactions that occur with increasing frequency as infants learn to crawl and walk, infants construct or elaborate upon a representation of others as intentional agents motivated by subjective internal states. These data provide a starting point for future research investigating the multidimensional influences of social and motor development and intention understanding.



## CHAPTER IV

### *GENERAL DISCUSSION*

The ability to understand others as intentional agents is both fundamental to human experience and foundational to development in social, cognitive, and linguistic domains (e.g., Baldwin & Moses, 2001; Tomasello, 1999). Recent research has shown that this cornerstone of social cognition has its roots early in infancy. Thus, the central goal of the current dissertation was to examine the development of this important concept during the first year of life. Specifically, this dissertation asked when and how infants develop an understanding of human behavior as guided by subjective internal states that underlie and are separate from actions and objects in the world. That is, when and how do infants develop an understanding of *intention*?

The marker of intention understanding used throughout this dissertation was the ability to reason about failed human actions. Failed actions were selected because they share an important, unique feature: in a failed action, there is a mismatch between the action's observable outcome and the intention that motivates it. Because the goal of a failed action is not apparent in the actor's movements or in the outcome achieved, reasoning appropriately about the goal of a failed action would not be possible without at least a rudimentary understanding that intentions exist independently of actions and objects. Thus, throughout this dissertation, failed action understanding is examined and contrasted with successful action understanding to reveal the development of intention understanding.

Two key studies examined an understanding of successful versus failed intentional actions in infants between the ages of 8 and 12 months. In Study 1, visual habituation research examining 8-, 10-, and 12-month-olds' understanding of directly comparable successful and failed reaching actions, I focused on two central questions. First, at what age do infants perceive failed actions as guided by intentions that are not

manifested in action? Does this ability emerge during the first year of life? Second, what is the relationship between reasoning about successful and failed actions? Does understanding failed actions (i.e., actions in which there is a mismatch between the underlying intentions and observed movements) represent a developmental advance over understanding directly comparable successful actions (i.e., actions in which underlying intentions are manifest in the observed actions)?

Results from Study 1 revealed a key developmental transition from approximately 8 to 10 months of age. Thus, Study 2 extended the first study to explore the process by which 8- and 10-month-olds learn about intentional actions and how this milestone is related to other contemporaneous developmental achievements. Eye-tracking methodology was used to examine infants' on-line processing and learning about the successful and failed reaching actions from Study 1. Moreover, performance on the experimental task was explored in relation to parent-report measures of infant motor (e.g., crawling, walking, means-end behavior production) and social behaviors (e.g., pointing, imitating, gaze following, joint attention).

Three central findings emerged from these studies. I discuss these findings in the following sections.

### **Finding 1: Infants Understand Failed Goal-Directed Actions in the First Year of Life**

The first main finding from the current studies is that, already within the first year of life (at 10 and 12 months), infants understand and can reason about failed reaching actions. This understanding was confirmed in two ways: first, through looking time responses indicating that infants encoded the failed reaching action in terms of its goal and not simply in terms of its surface perceptual features (Study 1); and, second, through patterns of anticipatory looking showing that infants predicted the goal of the reach even after a failed attempt (Study 2). These data extend prior work documenting failed action understanding in toddlers (15 and 18 months) through active, imitation tasks (e.g., Bellagamba & Tomasello, 1999; Carpenter et al., 1998; Meltzoff, 1995). Moreover, they complement a recent body of evidence documenting failed action understanding in young infants (Behne et al., 2005; Daum et al., 2008; Hamlin et al., 2009a, 2009b; Legerstee & Markova, 2008). Together these findings suggest that infants in their first year possess a

nascent understanding of failed actions as guided by intentions that are not manifested in action.

The question of precisely when this understanding emerges is subject to debate. Although the current studies documented failed action understanding at 10 but not 8 months, some recent studies have claimed to demonstrate the presence of this understanding at 8 months or even younger. Although these studies are subject to alternative explanations and thus may not provide compelling assessments of intention understanding (e.g., Hamlin, Hallinan, & Woodward, 2009a; Daum et al., 2008), one particular study merits further discussion. Hamlin, Newman, and Wynn (2009) showed infants a hand holding a ring repeatedly approach the top of a plastic cone in a failed attempt to place the ring on the cone. The hand and ring then bounced away from the top of the cone toward the floor. Infants were presented with two test events: one that was consistent with the trajectory information but inconsistent with the goal (i.e., the ring approached the cone then bounced away and was placed on the floor alongside the cone), and one that was consistent with the goal (i.e., the ring approached and was placed on the cone). Hamlin et al. found that 8-month-olds looked longer to the trajectory consistent/goal inconsistent event, suggesting they were able to infer the failed action's goal. A comparison of Hamlin et al. and the current studies raises important additional questions about what support infants need to interpret a failed action in this spirit.

Although the stimuli in Hamlin et al. and the current studies varied in a number of ways (e.g., whether or not the actor's face and body were visible, the type of failed action performed, the number of objects involved in the action), one particularly interesting difference concerns how close the failed attempt came to achieving its goal. In the studies presented in this dissertation, the actor's hand approached the ball, yet remained visibly distant: the hand did not come in contact with the ball. In the Hamlin et al. (2009) study, however, the ring made contact with the cone before it bounced away. This contact information may have played a crucial role in instantiating the goal of the action and, thus, facilitating infants' understanding of it. Future research should manipulate features such as contact with or distance from the goal and their influence on infants' failed action understanding.

More generally, the finding that infants understand intention at some point during the first year of life complements a rapidly expanding literature demonstrating impressive social-cognitive abilities in young infants. For example, research from a number of labs has now documented that by their first birthdays, infants appreciate the actions of others as rational, efficient, and goal-directed (Biro & Leslie, 2007; Csibra et al., 1999; Csibra, 2008; Gergely et al., 1995; Phillips & Wellman, 2005; Woodward, 1998). They possess a deep understanding of visual experience (Meltzoff & Brooks, 2008; Moll & Tomasello, 2004) and how that visual experience influences an agent's knowledge state (Luo & Baillargeon, 2007; Luo & Johnson, 2009; Tomasello & Haberl, 2003). Moreover, controversial evidence suggests that infants may even understand belief states (Surian, Caldi, & Sperber, 2007; for evidence in slightly older infants, see Onishi & Baillargeon, 2005). Overall, the emerging picture from the current studies and the larger literature is that social cognitive abilities in infants are extensive and early.

### **Finding 2: Failed-Action Understanding Develops Later than Successful-Action Understanding**

The second major finding from the current studies adds a caveat to the striking social cognitive abilities emerging in the first year of life. Results from both Studies 1 and 2 confirmed that failed action understanding, though present at 10 and 12 months, is not evident at 8 months of age. Importantly, 8-month-olds understand and can reason about a successful reaching action, but they fail to do so for a directly comparable failed-reaching action. This pattern of results was also demonstrated in two ways: first, through looking-time responses indicating that infants encoded the successful reaching action in terms of its goal, but not the parallel failed action (Study 1); and, second, through patterns of anticipatory looking showing that infants predicted the outcome of a successful reaching action, but did not show anticipatory looking after a failed attempt (Study 2). Thus, converging results from two different methodologies provide firm evidence that in the course of development, understanding successful goal-directed actions precedes understanding failed goal-directed actions.

Regardless of exactly when infants can understand failed reaching in some optimal situation, because the current studies used directly comparable successful- and failed-reaching conditions, these results support a developmental picture wherein a

rudimentary understanding of action as motivated by subjective internal states emerges from an antecedent understanding of action that does not go deeper than the surface relations between agents and objects. This pattern is consistent with other accounts in the field (e.g., Gergely & Csibra, 2003; Wellman & Phillips, 2001; Woodward, 1998). On this view, infants first understand goal-directed action without attributing intentional mental states to the actor's mind. Only later does action understanding become truly mentalistic. The crucial question of how developmental change from a surface level understanding to one that takes into consideration others' intentions occurs will be discussed below.

### **Finding 3: Failed- (but not Successful-) Action Understanding is Associated with Infants' Initiation of Joint Attention and Self-Locomotive Ability**

Third, Study 2 confirmed that the intentional action understandings revealed through the experimental manipulations in this dissertation are importantly related to behaviors, skills, and experiences of infants outside of the laboratory context. In particular, failed action understanding (as demonstrated by latency of looking to the ball in the eye-tracking task) was strongly associated with both infants' tendency to initiate bouts of joint attention with others and with their ability to locomote independently.

The first association affirms assumptions that have long been made in the field about the deep connection between joint attention activities and intention understanding (e.g., Bretherton, 1991; Carpenter et al., 1998; Corkum & Moore, 1995; 1998; Tomasello, 1999). Moreover, this finding is consistent with research documenting relations between specific social behaviors (e.g., pointing) and an understanding of those behaviors in others (Brune & Woodward, 2005; Woodward & Guajardo, 2002). Importantly, the present study is the first to my knowledge to find an association between intention and joint attention more broadly defined, suggesting that infants' understandings in the first year of life may go beyond what Woodward calls "relatively local pockets of knowledge about particular actions" (Woodward, 2009, p. 241; e.g., knowledge about the specific act of pointing or the specific act of reaching) and include a broader, more abstract notion of people as intentional agents (e.g., Tomasello, 1999).

This study is also the first to my knowledge to document a relation between infants' ability to self-locomote and their understanding of intention. These data fit

together nicely with a body of research showing the ability to self-locomote dramatically changes the ways in which infants experience their world and, in particular, the ways in which infants interact with the people and objects around them (e.g., Campos et al., 2000; Clearfield, in press). The findings suggest the intriguing possibility that emerging motor abilities may set in motion crucial further developments in intention understanding and joint attention.

Finally, the fact that these relations were found only in the failed reaching condition and not in the directly parallel successful reaching condition helps to validate three basic assertions of the current studies: (1) that reasoning about a failed goal-directed action requires a different understanding of human behavior than does reasoning about a successful goal-directed action; (2) that failed actions provide a better, more diagnostic test of infants' ability to understand intention; and (3) that an intentional understanding of human behavior demonstrated by failed action understanding emerges later in the first year of life, approximately between the ages of 8 and 10 months.

### **Strengths and Limitations of the Dissertation**

This dissertation presents its own unique set of strengths and limitations. Here, I focus on three special strengths and three important limitations.

*Strengths.* One distinct strength of this dissertation is the direct comparison made between successful and failed actions. By using directly parallel successful- and failed-reaching actions that differ only on the focal variable of whether or not the goal was completed, the current study was able to ascertain not only when failed action understanding comes online, but, additionally, how failed action understanding relates to successful action understanding. The close correspondence between these two kinds of actions also helped rule out alternative explanations for the data (e.g., that the means-end analysis required to interpret the events led to difficulty for the youngest infants or that differences in infants' familiarity with the actions explain condition differences).

A second strength of this dissertation is its use of converging methods. The studies uniquely combined looking-time and eye-tracking methods. Although habituation remains an extremely common technique for studying infant cognition, interpreting global looking-time data such as those derived from the habituation method is notoriously problematic (Aslin, 2007). For example, longer looking to the indirect-reach test event in

Study 1 could be explained in a number of ways (e.g., “surprise” at seeing an action that is inconsistent with the goal of the habituation action, a preference for looking at curvilinear reaches, or a robust familiarity preference for watching the arcing path shown during habituation). The additional use of eye-tracking techniques helped to choose among these alternative explanations by uncovering the microstructure of infants’ looking responses. In particular, in the current study, eye-tracking data revealed important information about predictive looking patterns and shifting patterns of attention as the successful- and failed-reaching actions unfolded over time. Thus, converging habituation and eye-tracking data solidified the conclusion that there are age-related differences in infants’ understanding of successful- and failed-reaching actions. Furthermore, the incorporation of a measure of infants’ experiences and abilities outside of the laboratory context helped to both validate the experimental tasks and provide unique insights into the process and potential mechanisms involved in the development of intention understanding.

A final key strength of this dissertation is its use of multiple age groups to gain insight into developmental change in intention understanding and its possible causes. To date, most studies of infant social cognition have taken the approach of seeking evidence for focal abilities at a particular point in time. This approach, while valuable, does not consider how these abilities may change as a function of time or other events in development. By comparing performance of infants at three ages (8, 10, and 12 months), however, the current dissertation helps to provide a fuller picture of both what develops in the second half of the first year and how that developmental process proceeds.

Overall, the combination of directly comparable successful and failed reaching actions, multiple age groups, and converging methods (both experimental and parent-report) make the findings of this dissertation especially compelling.

***Limitations.*** Of course there are limitations to this set of studies, as well. First, one limitation is that only one kind of goal-directed action—reaching—was examined. Reaching was selected for very specific reasons, including the frequency with which it occurs, the transparency of its goal-directedness, the ease with which it can be manipulated to be successful versus unsuccessful, and infants’ proficiency at producing reaches by 8 months of age (Thelen et al., 1993). Nevertheless, because only this one,

basic goal-directed action was used, conclusions about the generality of intention understanding in the first year of life must be limited. Indeed it might be argued that reaching is a special case of intentional action because it is so frequent and salient in infants' lives. It remains an open question how broadly the intentional framework 10- and 12-month-olds used to interpret intention in reaching action is extended.

Second, the precise nature of the video stimuli used in the current studies necessarily limited analysis of how infants distribute their attention among the key components of human action was possible. In particular, the fact that there was considerable overlap between the area in which the actor's head moved and the area in which his arm moved during the reaching action made it difficult to examine differential attention to the actor's face and reach as the actions unfolded over time. Thus, the question of how infants coordinate information from different sources in a visual event remains ripe for future research.

Finally, this study has several limitations related to the parent-report measure of infant motor and social abilities. First is the fact that assessments rest exclusively on parent reports and were not substantiated by independent observations. On the one hand, parents can be especially apt observers; they are in a unique position to observe their child, to note infrequent but important accomplishments, and to helpfully aggregate scattered samples of observations into informative composite appraisals. On the other hand, parents are not trained observers. Observational difficulty may have been particularly problematic in the case of the responding-to-joint-attention items and the items assessing means-end action abilities. These behaviors were likely difficult for parents to evaluate and may have been better assessed by an experimenter observing infants and their caregivers in a play context.

Second, due to its exploratory nature, the parent questionnaire contained a limited number of items. For example, only one crude measure of means-end action abilities was included. Incorporating more items assessing means-end action abilities, in particular, may have produced a more sensitive measure.

Finally, a major limitation of the analyses involving the questionnaire items is that they can only evaluate concurrent relations between infant motor and social behaviors and intention understanding. We cannot be certain about the direction of causation that



may account for the substantial correlations observed. For example, because we do not know whether infants began initiating joint attention first or understanding intention first, we can only speculate about whether joint attention reflects intention understanding or provides a context in which intention understanding develops. Longitudinal studies are needed to examine how the relations between understanding intention, initiating-joint-attention, and moving independently play out over the course of development.

In the next sections I examine two key issues related to the current investigation. The first concerns the larger context in which infants' intention understanding fits: what are the implications of infants' intention understanding in ontogeny and phylogeny? The second concerns the question of development: what accounts for the 8- to 10-month shift in intention understanding observed in the current studies?

### **The Importance of Intention Understanding in Ontogeny and Phylogeny**

What might be the larger implications of the finding that infants in the first year of life possess an understanding of intention? A central premise of this dissertation was that the development of intention understanding is a critical achievement that is foundational to human experience and essential for many aspects of development. In this section I provide three key reasons why intention understanding is important both in ontogeny and in phylogeny.

First, infants' understanding of intention lays the foundation for subsequent conceptual development. In particular, infants' understanding of intention is precursory to later theory of mind understandings, such as preschoolers' understandings of desire and belief. Several studies now show that infants' responses in habituation experiments that feature goal-directed actions predict their later performance on verbal theory of mind measures (Aschersleben, Hofer, & Jovanovic, 2002; Wellman et al., 2008; Wellman, Phillips, Dunphy-Lelii, & Lalonde, 2004; Yamaguchi, Kuhlmeier, Wynn, vanMarle, 2009). For example, infant attention to intentional action at 10- to 12-months was found to predict later theory of mind understanding at 4 years—even when IQ, language competence, and executive functioning at 4 years were controlled (Wellman et al., 2008). Infants' attention to non-social action displays, however, did not predict later theory of mind (Yamaguchi et al., 2009). These findings demonstrate continuity from infant social

cognition to preschool theory of mind. Moreover, they suggest that the early intention understanding documented in young infants in the current study may develop into explicit preschool understandings of people as mental beings.

A second major domain of development in which intention understanding plays an essential role is the domain of language. As Tomasello (2003) points out, at its core, language is an elaborate system through which one person attempts to manipulate the intentional or mental states of others. Thus, naturally, intention understanding is primary in the language acquisition process. In particular, research has shown that when young children learn new words, they do not simply relate the words they hear to the things they see. Instead, they look at the person who uttered the word, analyze her focus of attention and probable intentions, and then use this information to interpret the meaning of the word (e.g., Baldwin, Markman, Bill, Desjardins, Irwin, Tidball, 1996; Baldwin & Moses, 2001). The joint attention context that has been proposed to result from an understanding of intention is also known to facilitate language development by enabling parents and infants to achieve the social coordination necessary for language learning (Bruner, 1983). Research suggests that individual differences in the capacity of parent-child dyads to establish and maintain episodes of joint attentional focus are related to ensuing language development (Markus, Mundy, et al., 2000; Mundy & Gomes, 1998; Tomasello & Todd, 1983). Thus, intention understanding plays a critical role in infant language development, perhaps, in part, by positioning infants to engage in the kinds of social interactions that will help them to learn language.

Finally, an intriguing implication of intention understanding proposed by Tomasello and colleagues (2005) is that the ability to understand and share intentions forms the basic infrastructure for uniquely human, collaborative cultural practices. For an individual child, recognizing that others are motivated by subjective internal states allows them to take part in cultural interactions and to learn within a social environment. For the human species, intention understanding (together with a strong motivation to share psychological states with others) makes possible species-specific activities such as the creation and use of linguistic and mathematical symbols, tools and technologies, and complex social institutions such as marriage, religion, and government.

This proposal raises the interesting question of how much of intention understanding is indeed species-specific. To what extent do our nearest primate relatives also understand intention? Until recently it seemed that nonhuman primates construed agents in social-behavioral ways with very little, if any, understanding of them as intentional agents. However, over the last 10 years, accumulating data have provided a very different picture. Several studies now show that, like humans, nonhuman primates understand the actions of others not just in terms of surface behaviors but also in terms of the underlying goals and possibly intentions involved (for reviews, see Call & Tomasello, 2008; Rosati et al., 2009). For example, after familiarization with events in which a human agent reaches in an arcing path over a barrier that separates it from a goal object (very much like the successful reaching action in the current studies; see Figure 1), macaque monkeys (*Macaca* spp.) were found to look longer at the indirect- than the direct-test events (Rochat et al., 2008; see also Uller & Nichols, 2000; Uller, 2004; Wood et al., 2007). Complementary data come from more active/interactive paradigms. In extensions of work carried out with infants (Behne et al., 2005), chimpanzees (*Pan troglodytes*, Call et al., 2004) and capuchins (*Cebus* spp., Phillips et al., 2009) responded differentially to experimenter actions which were remarkably parallel on the surface, but had different underlying intentions (e.g., when an experimenter was unwilling to give them food—offering and withdrawing a grape teasingly—versus when she was unable but trying to give them food—repeatedly dropping the grape). These findings support the view that, like human infants, nonhuman primates possess a basic understanding of the goal-directedness of action.

In addition, studies show that nonhuman primates also understand that others see, hear, and know things. For example, in controlled situations chimpanzees, bonobos, gorillas, and orangutans all follow gaze to distant locations and around barriers (even when it requires physically reorienting their bodies) and they visually check back to verify the direction of the looker's gaze (e.g., Brauer et al., 2005; for reviews, see Call & Tomasello, 2008; Rosati et al., 2009). Data on nonhuman primate understanding of visual experience is particularly strong for chimpanzees and in the context of food competition (Hare, Call, Agnetta, & Tomasello, 2000; Hare, Call, & Tomasello, 2001). To illustrate, consider the following scenario: A subordinate chimpanzee was placed in a

room opposite a room with a dominant conspecific. Barriers were placed in a room in-between these two rooms. By hiding several pieces of food behind these barriers and varying whether both chimpanzees or only the subordinate one could observe the baiting, Hare and colleagues tested whether the subordinate understood the knowledge and visual experience of the dominant. Results showed that subordinates systematically avoided approaching food that the dominant was aware of and preferentially targeted food that the dominant was ignorant of (had never seen) or was misinformed about (had seen in one place but had not seen moved). Based on these data, it can be concluded that chimpanzees know that others see things, and, further, that they are aware of and pay attention to what others see and know.

Thus, it now seems highly likely that nonhuman primates and humans share some important intention understanding abilities. Moreover, the increasingly demonstrable overlap between infants and nonhuman primates in early intention understandings—often based on very similar tasks and measures—provides increasing reason to interpret the intention understandings of humans and nonhuman primates as more deeply, rather than merely superficially, similar. However, although chimpanzees (and some monkeys) understand action as intentional and understand something about the visual experience and even knowledge of others, nonhuman primates' intention understanding falls short of children's. First, nonhuman primates' understanding may be limited to competitive contexts, not more broadly applicable (e.g. to cooperative situations) as in children. Second, there is no evidence that nonhuman primates go beyond the distinction between knowledge and ignorance to represent the false beliefs of others (e.g., cases in which an actor believes the food is in one place when the observer knows that it is really in another), even in competitive situations (Krachun, Carpenter, Call, & Tomasello, 2009). Finally, and perhaps most importantly, in the human case, intention understanding is revealed as early as infancy in numerous acts of joint attention. For example, infants engage in triadic interactions with others around objects and engage in pointing, showing, and sharing (Carpenter et al., 1998); yet there is little if any evidence for behaviors like this in nonhuman primates (Carpenter et al., 1995; Tomasello et al., 2005).

In sum, although the intention understanding revealed in the current study is likely not unique to humans, its presence in infancy remains significant: The recognition

that others have subjective internal states that motivate their actions provides a platform for the ontogenesis of theory of mind, language, and culture in the human case.

### **The Question of Development: What Accounts for the 8- to 10-Month Shift in Intention Understanding?**

A focal goal of this dissertation was to gain insight into developmental change in intention understanding in the first year of life and possible causes of that change. Results of the current studies revealed that impressive and important change occurs between approximately 8 and 10 months in how infants interpret the intentional actions of others. In this section, I explore the question of what accounts for this change by examining contributors to infants' developing intention knowledge.

First, consider the understanding of successful action that is in place in 8-month-olds. Research from a variety of different theoretical perspectives and using a number of different paradigms has shown that early in the first year of life, infants represent certain actions as directed toward goal objects in overtly rational and efficient ways (Biro & Leslie, 2007; Csibra, 2008; Csibra et al., 1999; Gergely et al., 1995; Hofer et al., 2005; Luo & Baillargeon, 2005; Phillips & Wellman, 2005; Sodian et al., 2004; Woodward, 1998). That is, they can recognize when actions are directed at goal-objects and whether those actions take direct, efficient or indirect, non-optimal paths toward their goals. Importantly, research has shown that infants show an appreciation of such overt, successful goal-directed action as early as 3 months of age (Luo, in press), and even when the goal-directed agent is nonhuman (e.g., a self-moving box or a two-dimensional ball; Biro & Leslie, 2007; Csibra, 2008; Csibra et al., 1999; Gergely et al., 1995; Hofer et al., 2005; Luo, in press; Luo & Baillargeon, 2005). These results have been taken as evidence for the view that infants possess an innate, abstract psychological reasoning system that guides their interpretation of goal-directedness (e.g., Csibra & Gergely, 2007; Johnson, 2000; Leslie, 1994, 1995; Luo & Baillargeon, 2005; Premack, 1990). Although this perspective can account for infants' performance in the successful reaching condition, I believe a different theoretical account must be offered to explain how infants' understanding of action changes to become truly intentional between 8 and 10 months of age.

The proposal that has received the most empirical attention is that first-person agentic experience contributes to infants' knowledge about others. On this view, infants' first-hand experiences as intentional actors offer unique insight into the underlying intentional structure of others' actions (Barresi & Moore, 1996; Gallese & Goldman, 1998; Meltzoff, 2007; Tomasello, 1999; Woodward, 2009). Support for this general proposal includes natural concordances (e.g., at 4 to 5 months, the age at which infants begin to make intentional grasps themselves, infants begin to understand others' grasps as goal-directed; Thelen et al., 1993; Woodward, 1998), and correlations (e.g., variability in 10-month-olds' ability to produce means-end actions is related to differences in understanding those actions performed by others; Sommerville & Woodward, 2005). However, the most convincing evidence comes from experimental interventions. For example, in a study by Sommerville, Woodward, and Needham (2005), 3-month-olds—who are not yet skilled in producing goal-directed grasps and who do not respond to others' grasps as goal-directed—received training in which they were able to manipulate the movement of toys using Velcro mittens. After training, they watched events in which an experimenter (wearing mittens) performed object-directed grasps. Results showed that mittens experience changed infants' responses to the observed actions: After mittens practice, infants treated the experimenter's mittened reaches as goal-directed. These results support the conclusion that infants' own first-person actions provide them with important information about others' actions (see also Meltzoff & Brooks, 2008; Sommerville et al., 2008).

The mechanisms by which information is translated from action into perception remain unclear. However, one interesting possibility is that the tight relationship between action and perception has a neurological basis (Rizzolatti & Craighero, 2004). Specifically, so called “mirror neurons” have been shown to be activated when either producing an act or watching someone else perform the same act (Rizzolatti, Fogassi, & Gallese, 2001). Based on this observation, it has been suggested that mirror neurons may play a major role in learning about intentionality; however, note that the exact role that mirror neurons play remains under debate (e.g., Csibra, 2007; Hauser & Wood, 2010; Lyons, Santos, & Keil, 2006; Rizzolatti & Craighero, 2004).

Although this general approach of examining the role of first-person experience has proven very fruitful in revealing important ways in which action experience influences infants' perception of others, a first-hand experience account alone seems unlikely to explain the development of intention understanding observed in the current studies. Consider that even by 8 months of age, infants have accumulated a great deal of first-hand experience reaching for objects and, presumably, have also experienced many instances of failing to achieve their goals. Indeed, these experiences may contribute to the understanding they evidence in successful-reaching tasks of the sort used here. However, it remains to be seen whether first-hand experience reaching around barriers for and potentially failing to retrieve a ball changes infants' performance in this task. Experience with reaching failures may or may not contribute to learning about the intentions underlying others' failed actions.

A distinct yet related possibility is that, beyond the level of experience producing *specific* goal-directed actions, experience as an intentional agent more broadly may influence infants' views of others' intentionality. It has long been argued that at around 8 to 9 months of age, infants begin to behave in ways that are clearly intentional and, thus, gain first-hand experience of intentionality (e.g., Piaget, 1953). A major demonstration of this developmental achievement is the onset of the ability to crawl (e.g., Campos et al., 2000). The ability to locomote independently grants infants a new level of autonomy and freedom to act on their own intentions. Thus, the experience producing intentional self-locomotion may provide an especially salient and powerful type of first-hand experience that leads to broad insights about both their own and others' intentionality. The association that emerged in Study 2 between self-locomotion abilities and intention understanding provides preliminary support for this view. Future research should consider this possibility further.

Although self-produced actions have proven central, they are almost certainly only part of a large set of experiences that contribute to infants' developing intention knowledge. Another possibility that received preliminary support in the current study is that experiences in joint attentional interactions also contribute to infants' emerging understanding of intention. Although many 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), some (Barresi & Moore, 1996; Moore, 2006; Mundy & Newall, 2007) propose that infants use joint attention interactions to gain insight into the intentionality of others. Consider what happens in joint attentional episodes. Infants engage in rich object-centered interactions with others. Within such triadic interactions, infants follow gaze (Corkum & Moore, 1998), use others' emotional displays toward objects to guide their own actions in relation to those objects (Mumme, Fernald, & Herrera, 1996), imitate others' object directed actions (Meltzoff, 1988), and even direct others' attention through communicative gestures such as pointing (Carpenter et al., 1998; Liszkowski et al., 2004). In all cases, the infant's intentions become aligned with those of the interactive partner as they share attention, emotion, or action on an object. Initially, the job of maintaining the joint attentional interaction is the caregivers', and caregivers work hard to keep the interaction around the object engaging for infants (e.g., Brand, Baldwin, & Ashburn, 2002). By the beginning of the second year, however, through repeated interactions with others over objects, infants become experienced in coordinating their own intentional actions with those of others, and these interactions become more reciprocal. In the process, Moore and colleagues (Barresi & Moore, 1996; Moore, 2006) propose that this experience provides infants a special opportunity to integrate first- and third-person information and construct representations of others' intentionality.

On this view, one likely interpretation of the developmental pattern observed in the current studies is that triadic interactions taking place with increasing frequency between 8 and 10 months provide infants with important opportunities to discover others' intentions. This view is supported by the correlational analyses showing an association between intention understanding and infants' tendency to initiate joint attention interactions with others. One possibility is that infants who have had more experience coordinating their own intentional actions with others in triadic interactions may be more likely to both initiate joint attention interactions and show an understanding of intention. On this view, the relation between initiating joint attention and intention understanding is driven by a third variable—experience in triadic interactions. Another possibility is that infants who are more likely to initiate joint attention (perhaps because of greater social motivation or more advanced self-locomotion) gain more experience in triadic



interactions and thus develop firmer representations of intention. In either case, the explanation for what contributes to infants' developing intention knowledge is experience in social interactions around objects. This remains a strong hypothesis that future research should consider more fully.

A final possible contributor to the development of intention understanding that has received considerably less empirical attention and is ripe for future research, is infants' observational analysis of others' observable actions. Wellman and Phillips (2001) proposed that analyses of overt, observable, intentional human actions may provide an important source of information for the development of intention understanding. One intriguing possibility is that observing *failed* human actions—in particular, failed actions whose intentions are relatively transparent, such as failed reaches—may provide infants with initial insights into the fact that actions are distinct from the intentions that motivate them. In other words, seeing failed attempts that are close approximations to an otherwise transparent goal-directed action (e.g., almost reaching a ball) may help infants discover the hidden intentions underlying human action. This proposal raises the following empirical question: Could infants who do not yet understand intention be taught to do so through observing repeated failed reaching attempts that closely approximate transparent goal-directed actions? The experimental paradigm in Study 2 provides one way to test this hypothesis. Although systematic learning was not observed in the 8-month-olds in Study 2 of the current dissertation, variations on the observed actions could help to facilitate learning. For example, instead of watching the same exact failed action repeatedly, infants could be shown failed reaching actions that vary in their path to the ball (e.g., over, behind, and in front of the barrier). In addition, infants could be shown failed reaches that differ in their contact with or distance from the goal object (e.g., grasping but dropping vs. barely touching vs. remaining visually distant from the ball; see also Hamlin et al., 2009). Finding that modifications such as these or a more sustained regimen of observing failed actions lead infants to anticipate the outcome of the failed action and generalize that prediction to a new context would provide support for the hypothesis that important learning about intention could occur through analyses of others' failed actions.

To summarize, the current studies provide strong evidence suggesting that a transition occurs between 8 and 10 months in how infants interpret intentional actions. Although the understanding present in young infants is consistent with the possibility that infants are born equipped with an abstract computational system for reasoning about goal-directed actions (e.g., Csibra & Gergely, 2007; Johnson, 2000; Leslie, 1994; Luo & Baillargeon, 2005; Premack, 1990), a different theoretical account must be offered to explain how infants' understanding of action changes in the second half of the first year to become truly intentional. Two strong candidate mechanisms of change that have received some support include first-hand experiences as an intentional agent and experience in rich, object-centered interactions with others. Both of these processes may well help infants discover the hidden intentions underlying human action by highlighting the concordance between infants' own actions and intentions and the actions and intentions of others. An additional mechanism of change (inspired by the analysis of anticipatory looking within an observational context in Study 2), wherein infants learn about the distinction between intentions and actions through observing failed action attempts also deserves future investigation. The questions of how these mechanisms work together and, in particular, how they enrich or build upon infants' earlier understandings remain important questions for future research. Such systematic research is made feasible by and can build upon the methods and findings provided in the present research.

Figure 1. Depiction of the action events in Study 1: (a) Successful-reaching and failed-reaching habituation events; (b) Direct-reach and indirect-reach test events.

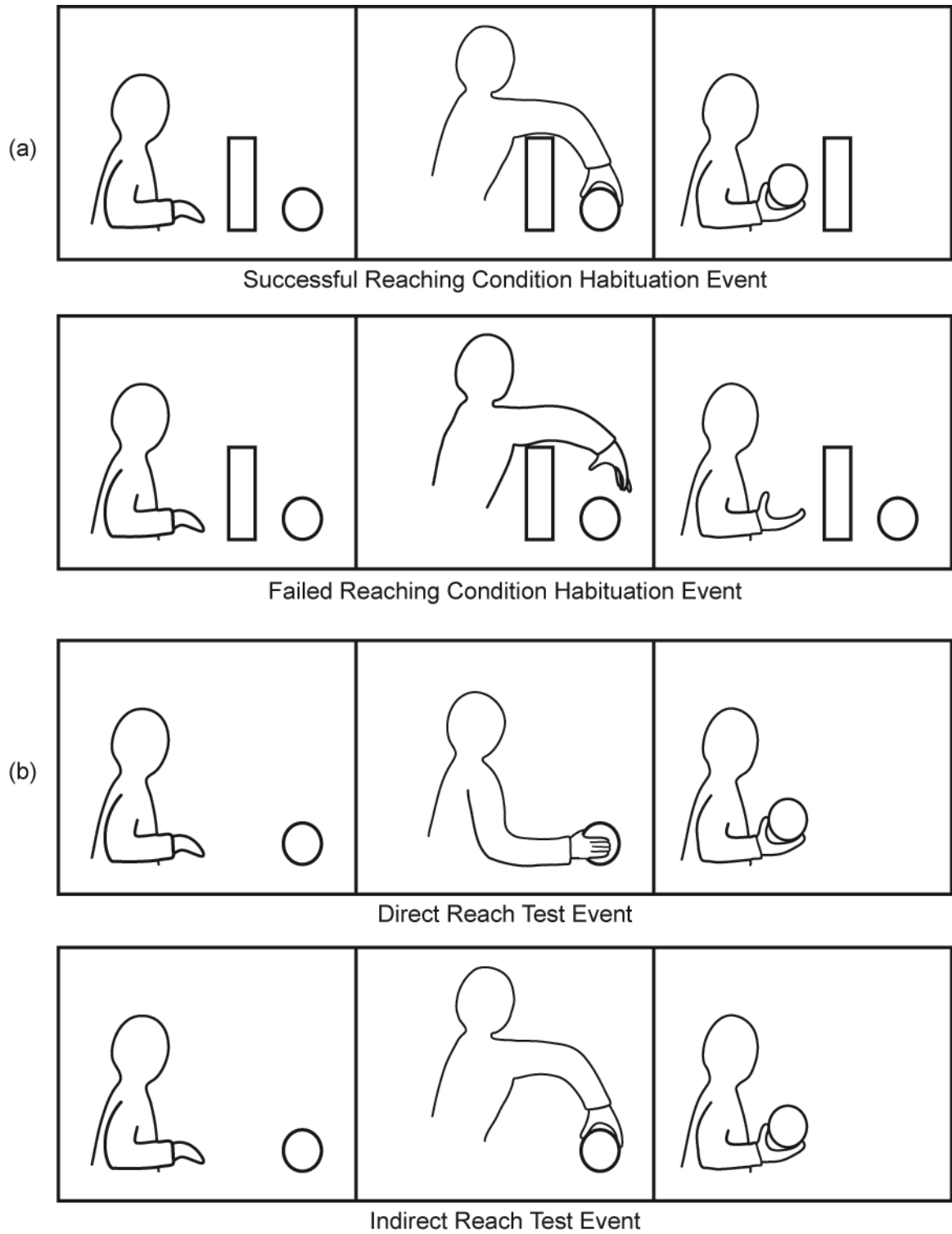


Figure 2. Study 1: Average looking time ( $\pm$  standard error) to the direct- and indirect-reach test events by condition and age group.

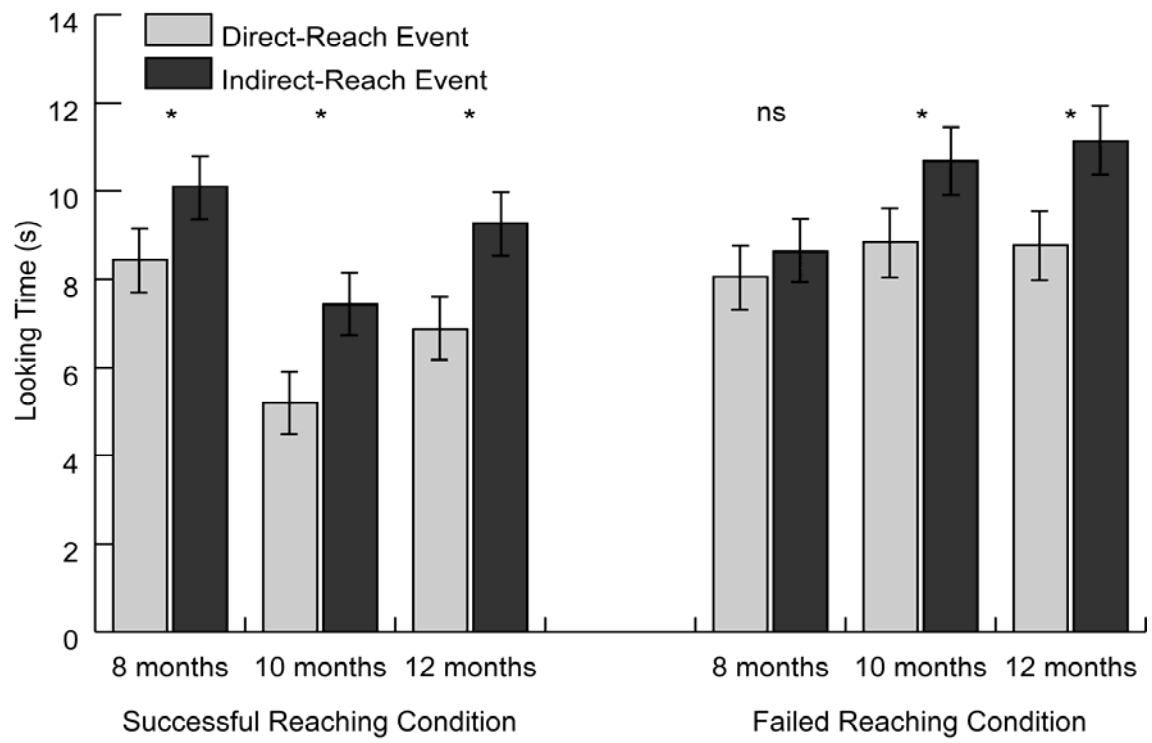


Figure 3. Studies 1a and 1b: Average looking time ( $\pm$  standard error) to the direct- and indirect-reach test events by study and age group.

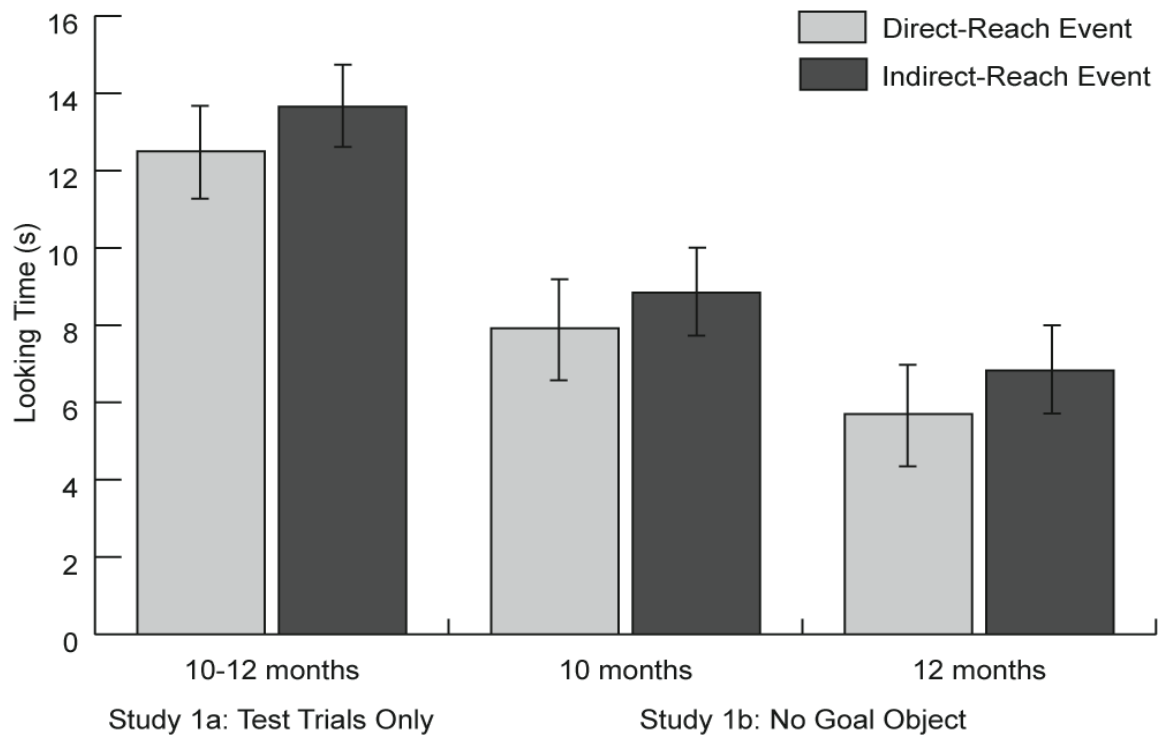
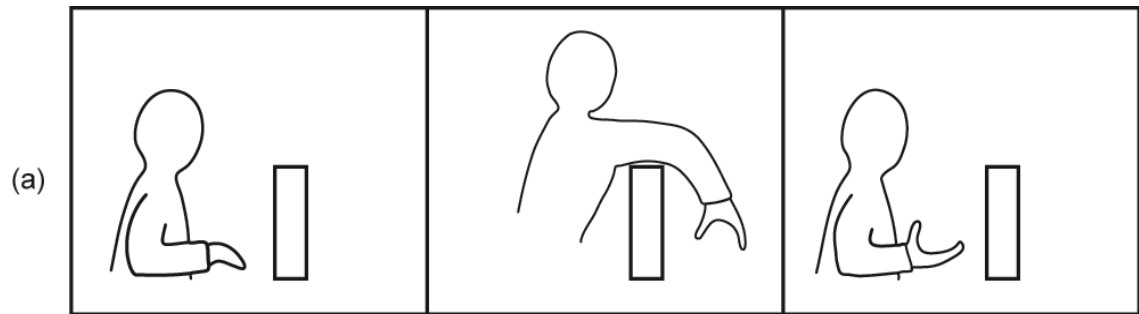
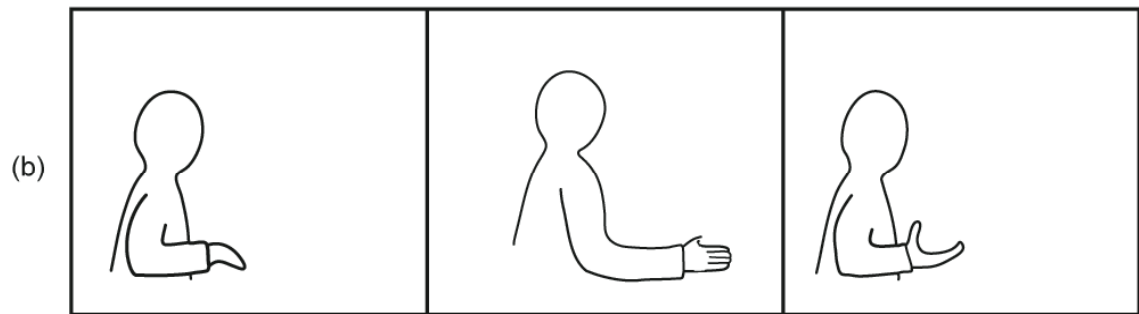


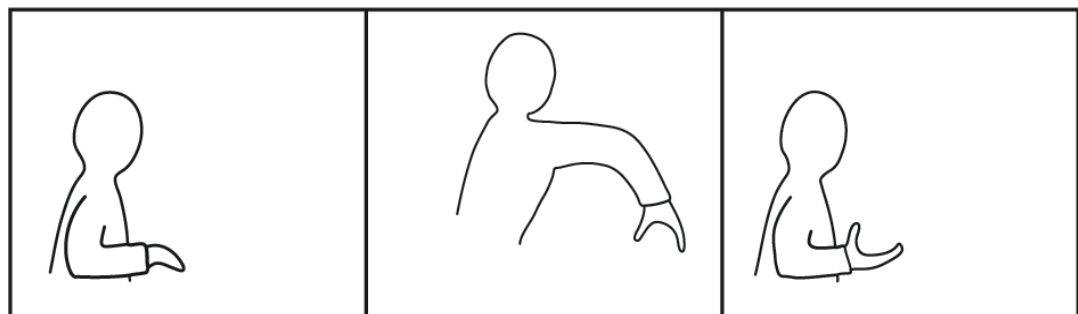
Figure 4. Depiction of the action events in Study 1b: (a) Habituation event; (b) Direct-reach and indirect-reach test events.



Habituation Event: No Goal Object



Direct Reach Test Event: No Goal Object



Indirect Reach Test Event: No Goal Object

Figure 5. Depiction of the areas of interest (AOIs) for the successful- and failed-reaching familiarization events in Study 2.

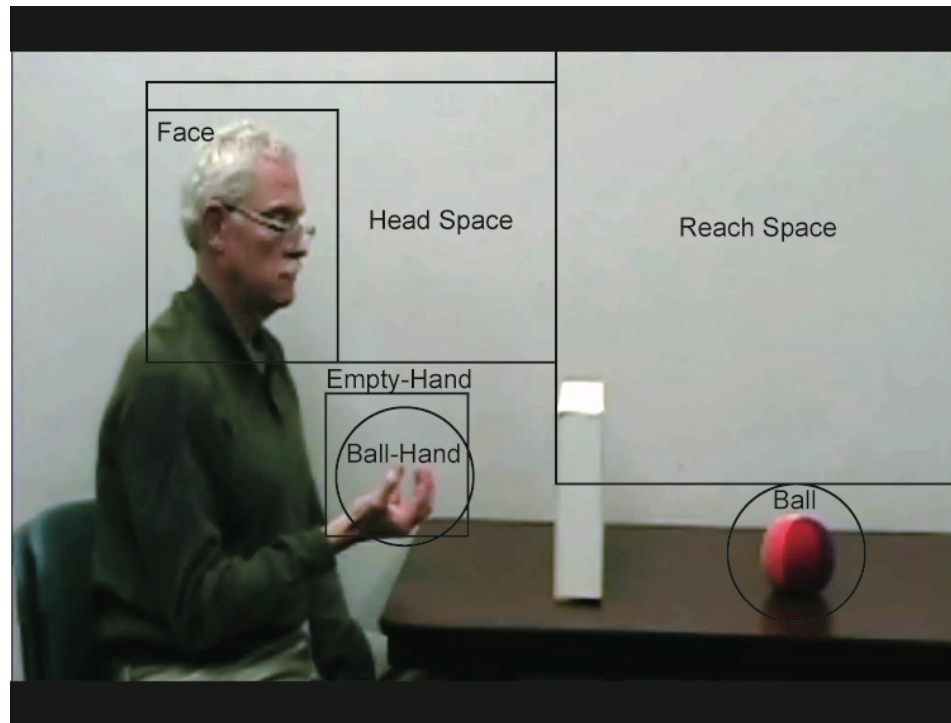
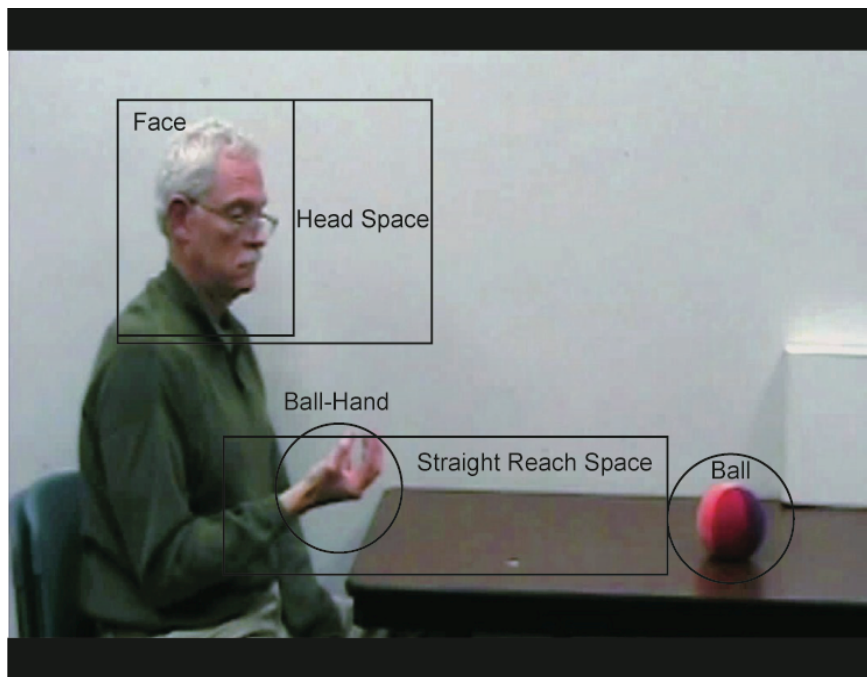
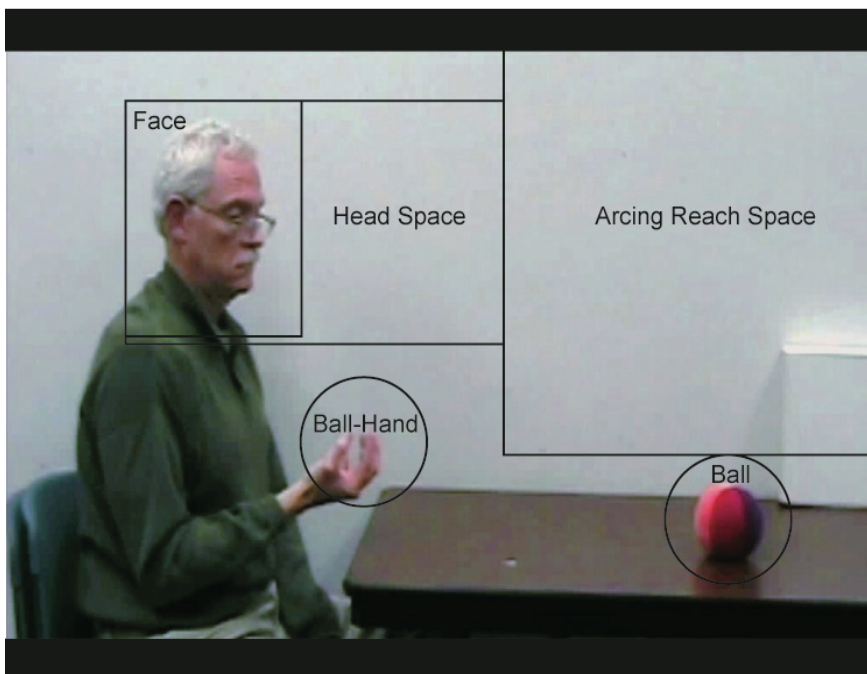


Figure 6. Depiction of the areas of interest (AOIs) for the test events in Study 2: (a) Direct-reach test event; (b) Indirect-reach test event.



(a) Direct-Reach Test Event



(b) Indirect-Reach Test Event



Figure 7. Study 2: Mean proportion of anticipatory looks ( $\pm$  standard error) to the Ball Area of Interest (AOI) during the familiarization phase as a function of triad, age group, and condition.

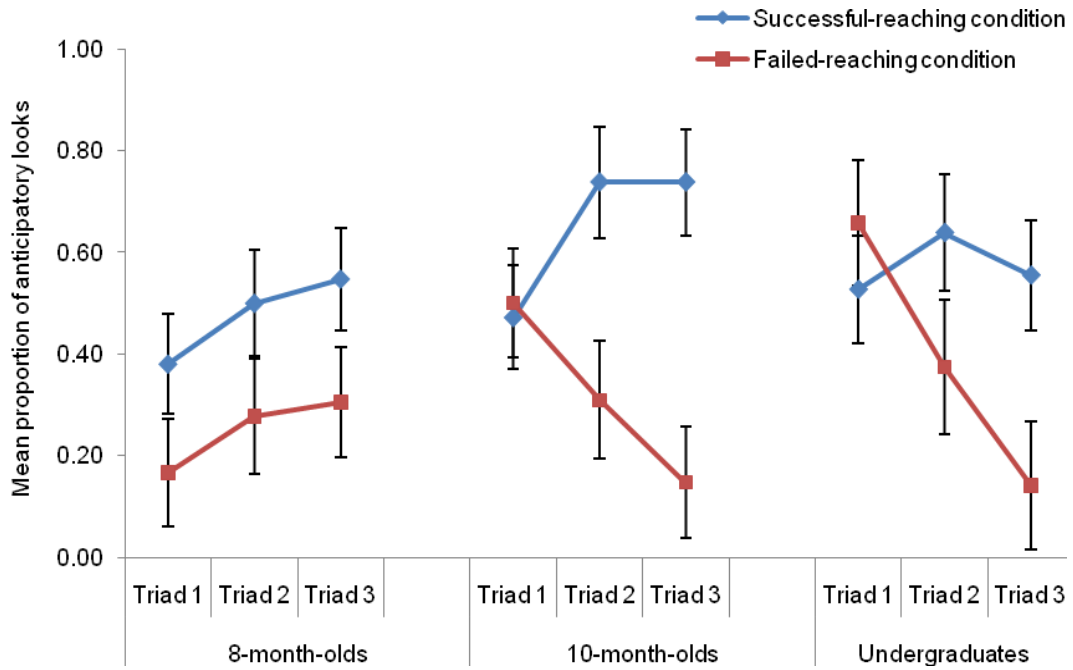


Figure 8. Study 2: Mean latency of looking ( $\pm$  standard error) to the Ball Area of Interest (AOI) during the familiarization phase as a function of triad, age group, and condition. Points below the anticipatory look cut-off are predictive looks.

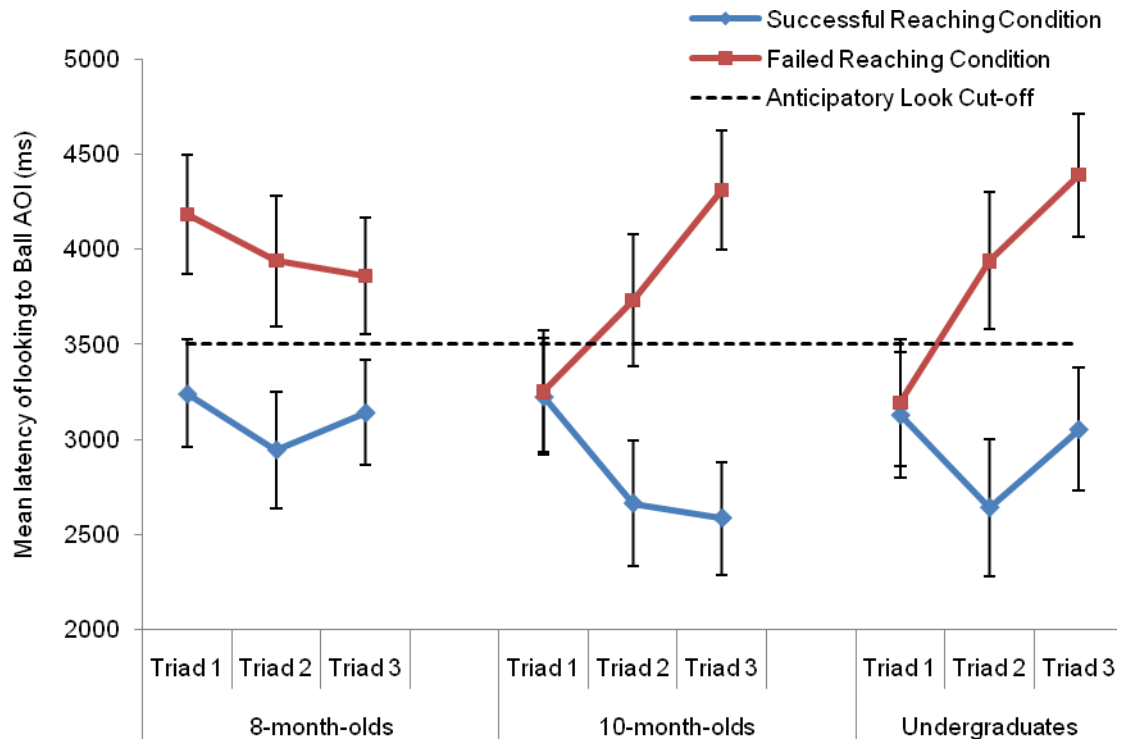


Figure 9. Study 2: Cumulative proportion of trials ( $\pm$  standard error) on which participants in the successful- and failed-reaching conditions looked at the Ball Area of Interest (AOI) during Triad 1 of the familiarization phase: (a) 8-month-olds; (b) 10-month-olds; (c) Undergraduates.

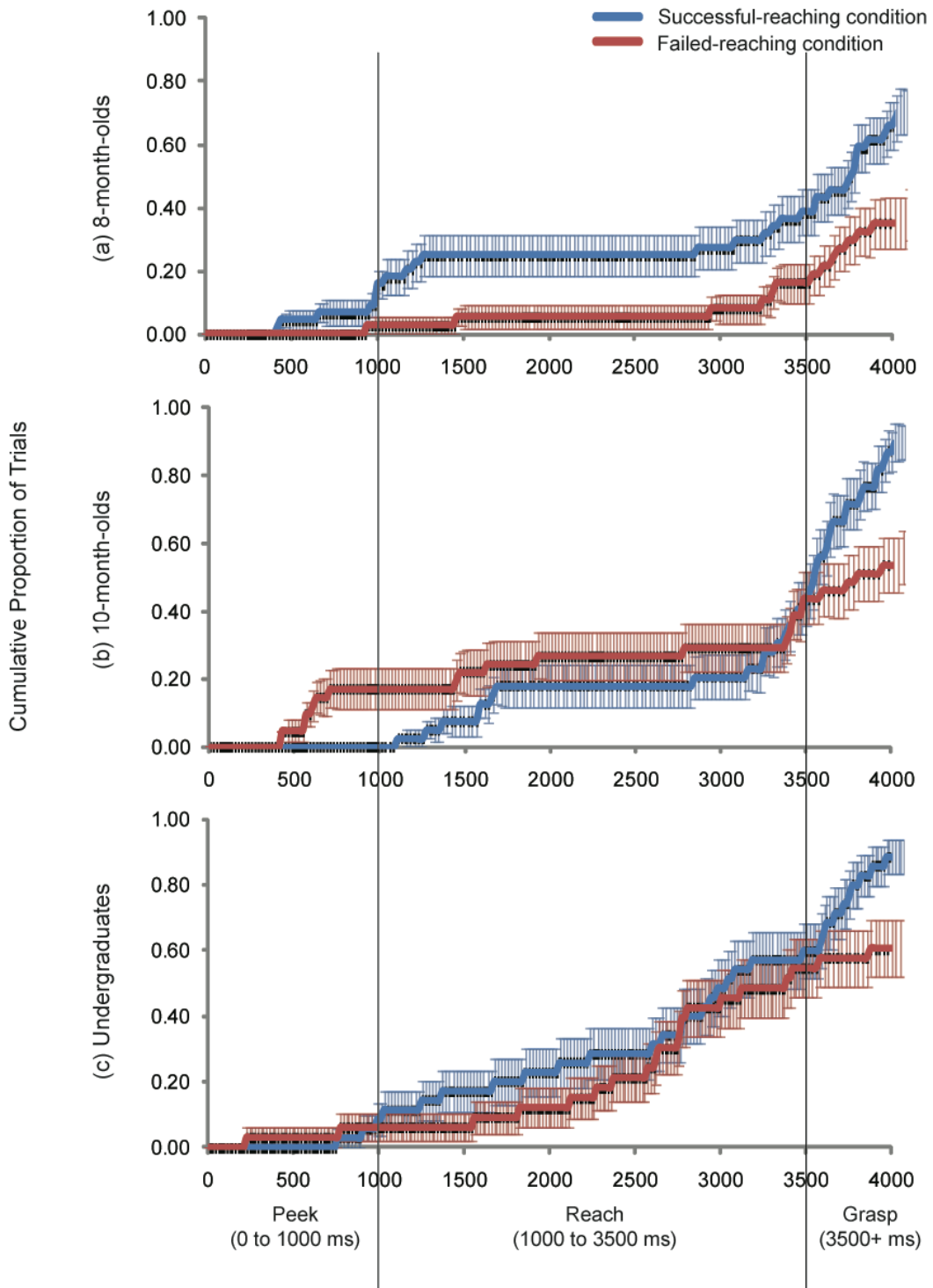


Figure 10. Study 2: Proportion of trials on which participants in the successful- and failed-reaching conditions looked at each area of interest (AOI; Ball, Head Space, Reach Space) during the Peek, Reach, and Grasp segments of the familiarization phase: (a) 8-month-olds; (b) 10-month-olds; (c) Undergraduates.

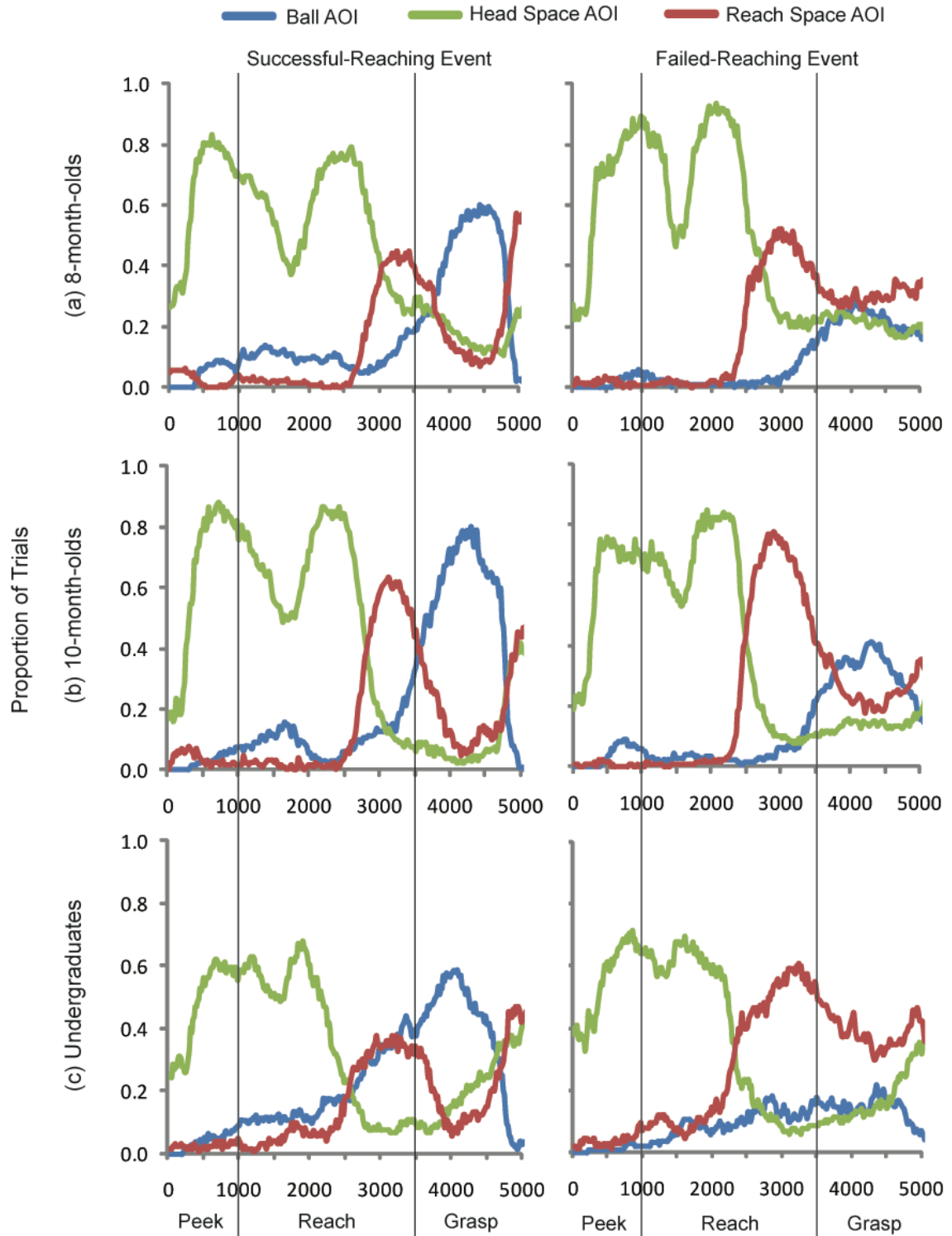


Figure 11. Study 2: Mean proportion of anticipatory looks ( $\pm$  standard error) to the Ball Area of Interest (AOI) during the test phase (direct- and indirect-reach events combined) as a function of age group and familiarization condition.

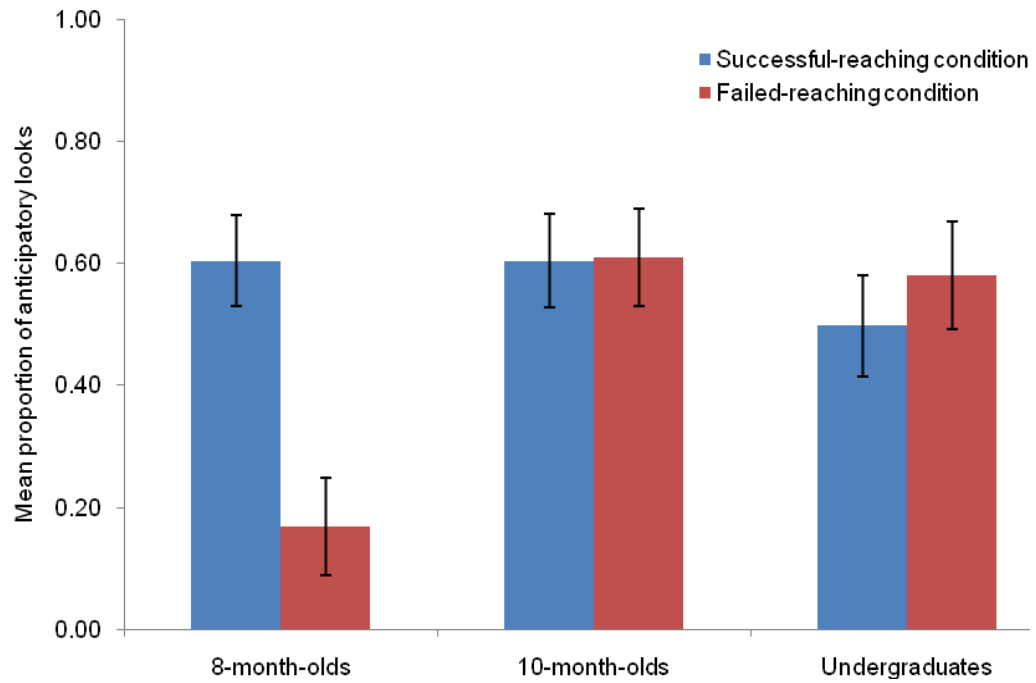


Figure 12. Study 2: Mean latency of looking ( $\pm$  standard error) to the Ball Area of Interest (AOI) during the test phase (direct- and indirect-reach events combined) as a function of age group and familiarization condition.

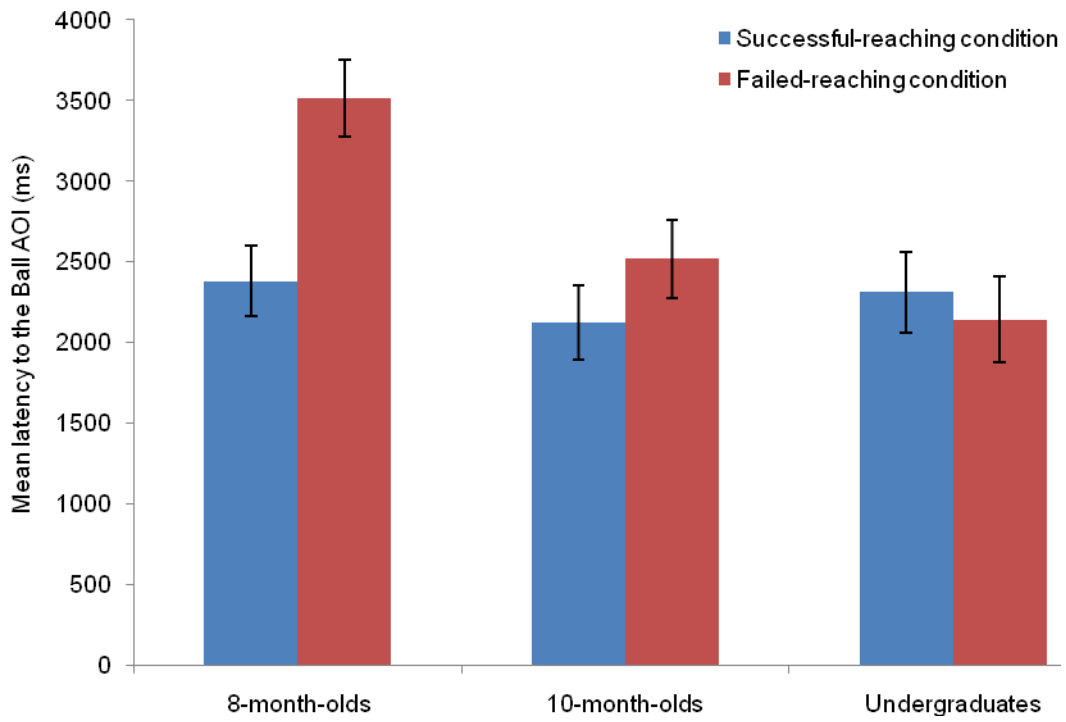


Figure 13. Study 2: Cumulative proportion of trials ( $\pm$  standard error) on which participants in the successful- and failed-reaching familiarization conditions looked at the Ball Area of Interest (AOI) during the direct- and indirect-reach test events: (a) 8-month-olds; (b) 10-month-olds; (c) Undergraduates.

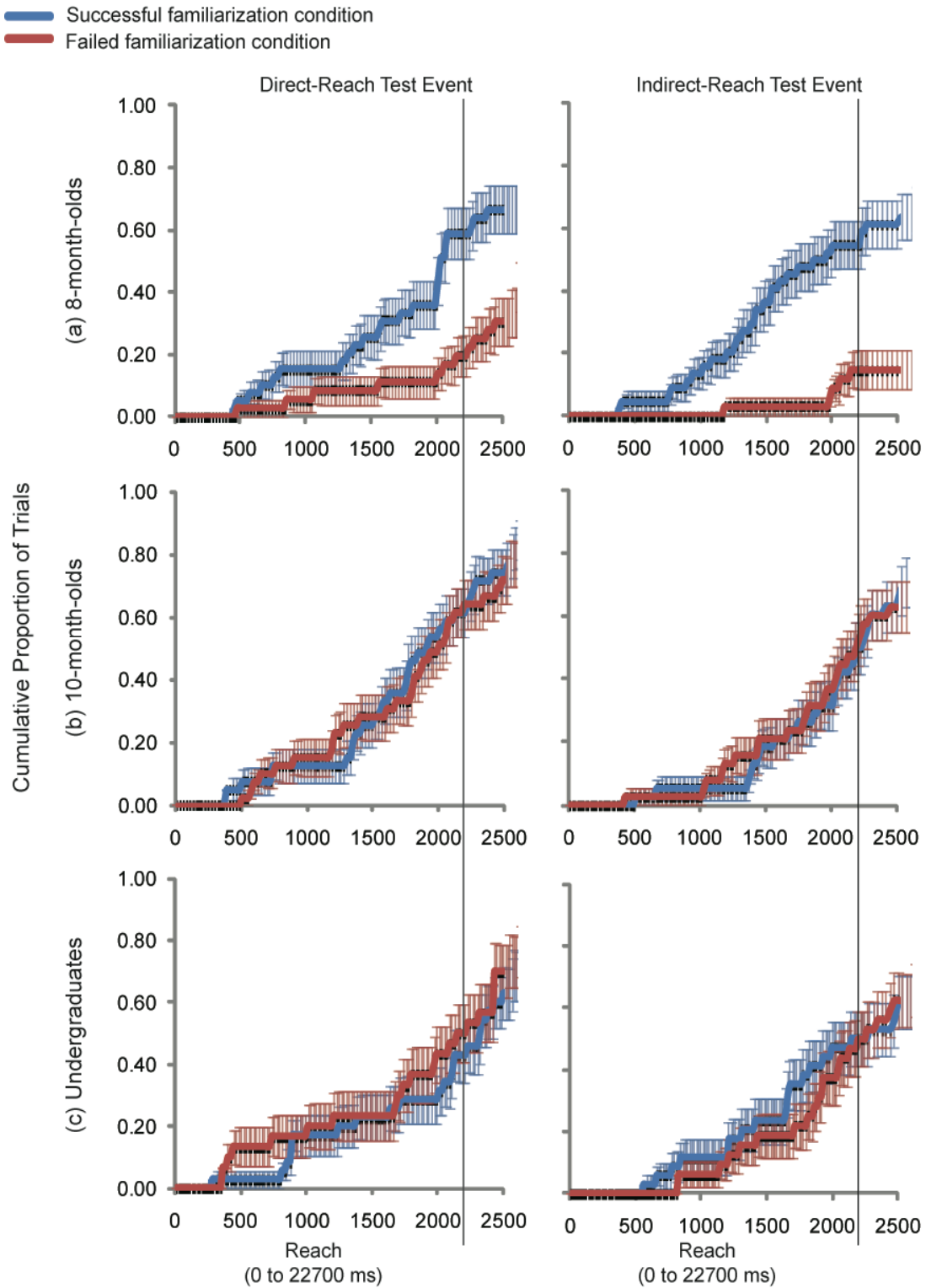


Figure 14. Study 2: Proportion of trials on which participants familiarized with the successful-reaching action looked at each area of interest (AOI; Ball, Head Space, Composite Reach Space) during the Reach and Grasp segments of the direct-and indirect-reach test events: (a) 8-month-olds; (b) 10-month-olds; (c) Undergraduates.

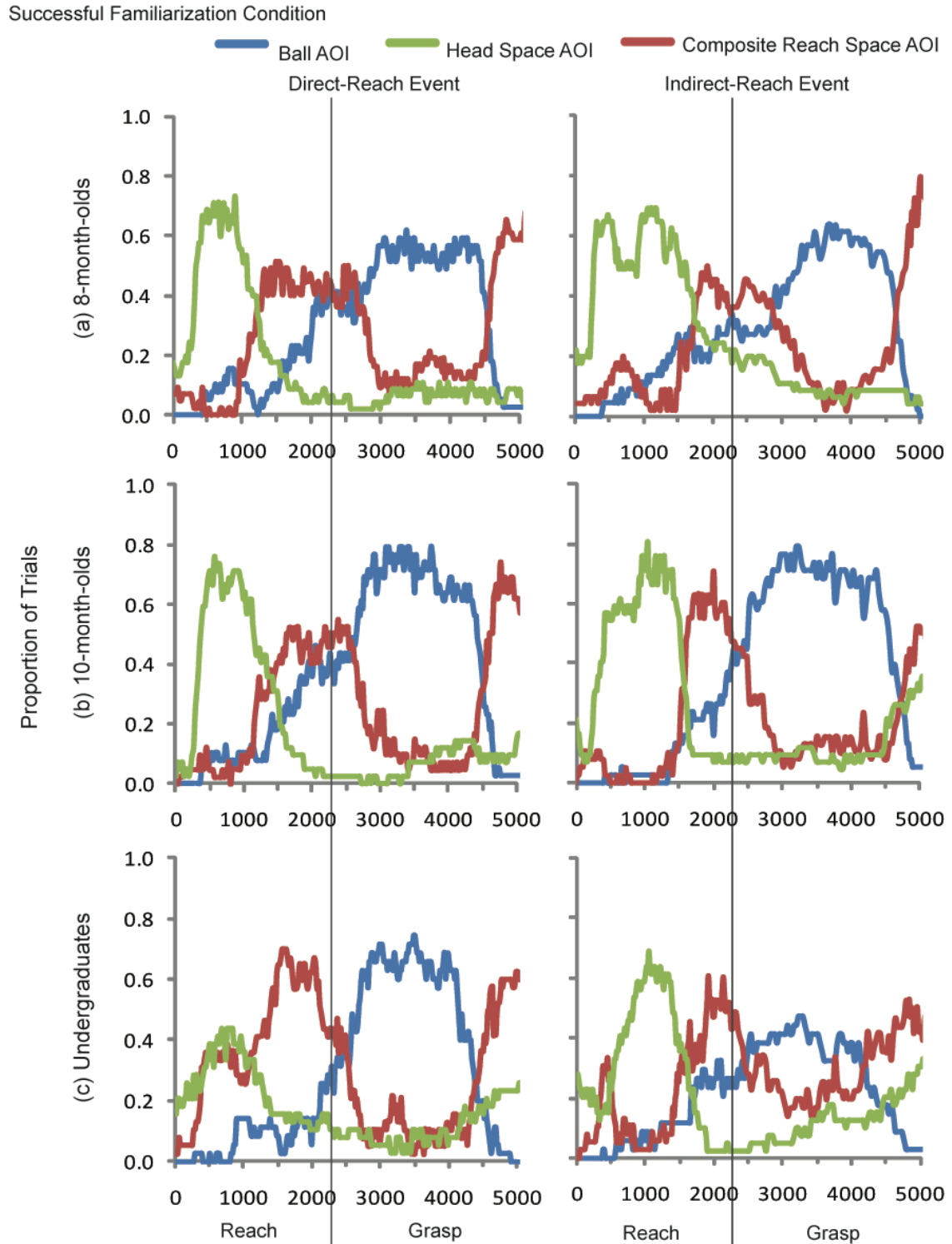




Figure 15. Study 2: Proportion of trials on which participants familiarized with the failed-reaching action looked at each area of interest (AOI; Ball, Head Space, Composite Reach Space) during the Reach and Grasp segments of the direct-and indirect-reach test events: (a) 8-month-olds; (b) 10-month-olds; (c) Undergraduates.

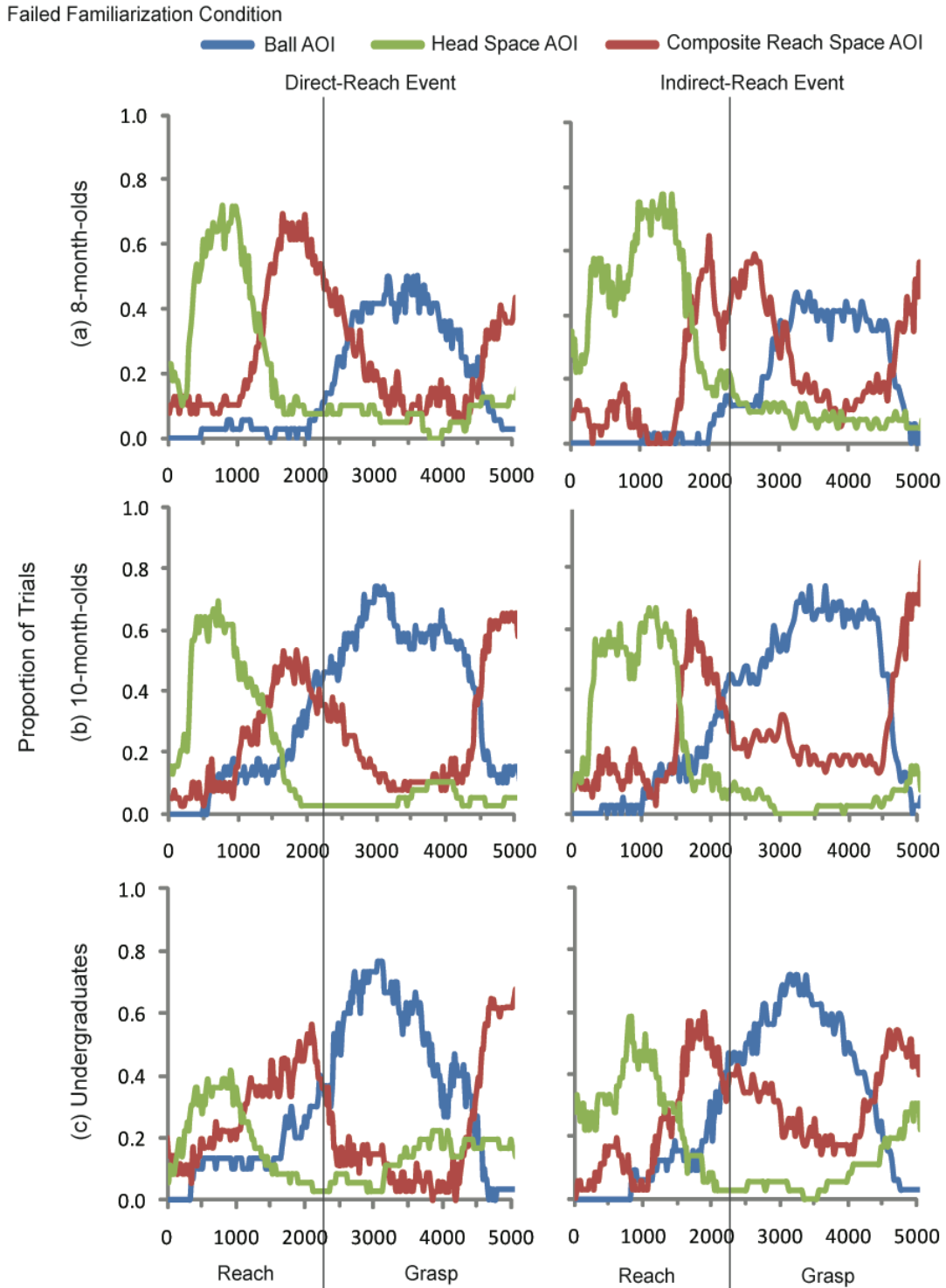


Table 1.  
*Factor Loadings for Final 11 Joint Attention Items (Varimax Rotation)*

Factor	Items and Factor Loadings	$\alpha$
Initiating-joint-attention	Does your child use his/her index finger to point to ask for something? (.69)	.74
	Does your child use his/her index finger to indicate interest in something? (.78)	
	Does your child show you objects by bringing them over to you or extending his/her arm to show you what he/she is holding? (.79)	
	Does your child reach out and give you an object that he/she is holding? (.63)	
	Does your child imitate you? (e.g., if you make a face, does your child imitate it?) (.45)	
	Does your child try to attract your attention to his/her own activity? (.54)	
Responding-to-joint-attention	If you point at a toy across the room, does your child look at it? (.50)	.60
	If you look at something across the room, does your child look at it? (.76)	
	If you and your child are playing with an object together, does he/she look back and forth between you and the object? (.54)	
	Does your child look at things you are looking at? (.70)	
	Does your child look at your face to check your reaction when faced with something unfamiliar? (.46)	

Table 2.

*Intercorrelations between Age and the Infant Behavior Measures*

Variable	Means-end ability	Initiating-joint-attention	Responding-to-joint-attention	Age
Self-locomotion	.158	.450**	.192	.568**
Mean-end ability		.164	.426**	.309*
Initiating-joint-attention			-.075	.450**
Responding-to-joint-attention				.239

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

Table 3.

*Correlations between Infant Behavior Measures and Latency to Look at the Ball Area of Interest (AOI) in Familiarization Triad 1 and during the Test Events*

Variable	Successful Condition		Failed Condition	
	Triad 1	Test	Triad 1	Test
Self-locomotion	-.022	-.115	-.607**	-.639**
Means-end ability	-.073	.014	-.076	.199
Initiating-joint-attention	.252	.061	-.526*	-.430*
Responding-to-joint-attention	-.238	-.097	.144	.264

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

Table 4.

*Partial Correlations (Controlling for Age) Between Infant Behavior Measures and Latency to Look at the Ball Area of Interest (AOI) in Familiarization Triad 1 and the Test Events*

Variable	Successful Condition		Failed Condition	
	Triad 1	Test	Triad 1	Test
Self-locomotion	.012	.179	-.544*	-.597**
Means-end ability	-.075	.145	.144	.320
Initiating-joint-attention	.383	.358	-.465*	-.363
Responding-to-joint-attention	-.233	-.074	.365	.455

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

## APPENDIX

**Instructions:** Please read the following questions and indicate with an X whether your child performs each behavior “Often”, “Sometimes”, or “Not Yet.” Keep in mind that this form is given to infants at a variety of ages, so don’t worry if your child does not yet do these behaviors!

Question	Often	Sometimes	Not Yet
Does your child use his/her index finger to point to ask for something? <sup>1</sup>			
Does your child use his/her index finger to point to indicate interest in something? <sup>1</sup>			
Does your child show you objects by bringing them over to you or extending his/her arm to show you what he/she is holding? <sup>1</sup>			
Does your child reach out and give you an object that he/she is holding? <sup>2</sup>			
Does your child imitate you? (e.g., if you make a face, does your child imitate it?) <sup>1</sup>			
Does your child respond to his/her name? <sup>1</sup>			
If you point at a toy across the room, does your child look at it? <sup>1</sup>			
If you look at something across the room, does your child look at it? <sup>2</sup>			
If you and your child are playing with an object together, does he/she look back and forth between you and the object?			
Does your child look at things you are looking at? <sup>1</sup>			
Does your child try to attract your attention to his/her own activity? <sup>1</sup>			
Does your child look at your face to check your reaction when faced with something unfamiliar? <sup>1</sup>			
Does your child search for objects that are covered up or partially covered up? (e.g., lift a cloth to retrieve a hidden object?)			
Does your child reach for objects that are out of reach?			
Does your child crawl? If yes, when did he/she start doing so? _____			
Does your child pull him/herself to a standing position? If yes, when did he/she start doing so? _____			
Does your child walk with support? If yes, when did he/she start doing so? _____			

Does your child walk independently? If yes, when did he/she start doing so? _____			
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<sup>1</sup> Taken or modified from the Modified Checklist for Autism in Toddlers (**M-CHAT**<sup>TM</sup>; Robins, Fein, & Barton, 1999)

<sup>2</sup> Taken or modified from the Communication and Symbolic Behavior Scales Development Profile Infant-Toddler Checklist (Wetherby & Prizant, 1998, 2002)

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