CHAPTER SIX

The Emergence of Intention Attribution in Infancy

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Contents

Abstract

Perception of the social world in terms of agents and their intentional relations is fundamental to human experience. In this chapter, we review recent investigations into the origins of this fundamental ability that trace its roots to the first year of life. These studies show that infants represent others' actions not as purely physical motions, but rather as actions directed at goals and objects of attention. Infants are able to recover intentional relations at varying levels of analysis, including concrete action goals, higher order plans, acts of attention, and collaborative goals. There is mounting evidence that these early competencies are strongly influenced by infants' own experience as intentional agents. Action experience shapes infants' action perception.

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1. Introduction

Central to human experience is the perception that we live in a world of intentional agents. We see others' actions not as raw physical movements, but rather as structured by intentions. The intentional lives of our social partners are as real to us as the physical world in which they play out. To illustrate, on seeing a player chase a soccer ball across a field, we conceive of the event not in terms of sheer physical movements, but rather in terms of the player's goal to propel the ball and her more abstract goals to evade the players on the other team, score and win the game. Even though the ball traverses the field along a similar trajectory to the player, we do not view its movements in the same way.

This cornerstone of social perception is pervasive in adults' memory for, reasoning about, and communication of event information (Dennett, 1987; Heider, 1958; Malle, Moses, & Baldwin, 2001; Shipley & Zacks, 2008). For example, on viewing continuous events in which people perform common actions, adults readily parse the events into units that correspond to the goals that structure the agent's actions (Zacks, Tversky, & Iyer, 2001). Further, when relating event information in discourse, adults and children structure their narrative with respect to the goals and higher order plans embedded in the events (Trabasso, Stein, Rodkin, Munger, & Baugh, 1992). Although there are striking cross-cultural variations in social reasoning, the spontaneous perception of others as intentional agents appears to be universal across human cultures (Lieberman, Jarcho, & Obayashi, 2005; Lillard, 1998; Norenzayan & Nisbett, 2000).

Barresi and Moore (1996) described the perception of others' actions as being structured by *intentional relations*: People conceive of others' actions in terms of the agent's intentional relation to a real or abstract entity. To illustrate, when the soccer player turns to face an opponent, observers understand her actions as indicating a relation between her and the other player—she *sees* the opponent. When she drives the ball down the field, observers view her actions in relation to the physical goal, as well as the more abstract goals of scoring a point and winning the game. Intentional relations range from the concrete (getting, wanting, or seeing the ball) to the abstract (wanting to win the game, imagining tomorrow's match, or regretting yesterday's loss). Adults describe these relations via a large mental state lexicon that captures distinct kinds of intentional relations, including relations to goal objects, relations to objects of attention, and relations to mental entities (ideas, plans, beliefs). As Barresi and Moore noted, this rich and varied set of attributions has, at its core, the understanding that human behavior is best understood not as isolated movements through space, but rather as movement in relation to something (a goal, an object of attention, etc.).

In this chapter, our focus is the development of this cornerstone of social perception. As shorthand, we will use the term *intention-reading* to describe the perception of others' actions as organized by intentional relations. Developmental psychologists seek to understand the origins of basic human abilities. Because it is so basic to our everyday perception of reality, the emergence of intention-reading has long been a focus in developmental work. Interest in this topic can be traced back to the earliest days of the field (Piaget, 1929), and this area is still a hotbed of current research and debate.

There is another reason for this prolonged and intense scientific interest in the development of intention-reading: this ability plays a foundational role in broader developmental processes. Much of cognitive, social, and linguistic development depends on the child's ability to discern the intentions of social partners. To illustrate, when 18-month-old children imitate the actions of others, they do not simply reproduce the movements they observe. Rather, they infer the actor's probable intentions and seek to reproduce them. Indeed, Meltzoff (1995) showed that 18-month-old children reproduce the model's intent, even when the model has failed to achieve her goal, and thus they have never actually seen the intended outcome. Similarly, when children at this age learn new words, they do not simply map the words they hear to the objects they see. Rather, they seek and use information about the speaker's focus of attention and intentions to interpret the words she utters (Baldwin & Moses, 2001; Tomasello, 1999). As one example, Baldwin has shown that 18-month-old children infer that an adult's utterances pertain to the object of her attention, even when their own attention is directed elsewhere (Baldwin, 1989). Children engage in a similar process of intentional analysis when making sense of others' emotional signals to decide which objects are safe and which are dangerous (Moses, Baldwin, Rosicky, & Tidball, 2001).

Findings like these support two conclusions. First, the ability to discern intentional relations is critical for many early acts of social learning. This ability provides a lens for extracting the meaningful structure in action (Woodward, 2003b, 2005a). Second, this ability is robust by the middle the second year of life, and thus tracing its developmental origins requires that we look still earlier. In the past decade, researchers have devised methods for tapping preverbal infants' analysis of others' actions. The results of this work have provided strong converging evidence that sensitivity to intentional relations emerges early in the first year of life. In Section 2, we review these findings in order to characterize infants' understanding of intentional relations during the first year of life. This review motivates the question addressed in the second half of the chapter, namely, how intention-reading originates in human ontogeny.

2. Intentional Analysis in Infancy: An Overview

Infants seem socially smart to the adults who interact with them. Young infants are intensely interested in other people, and they engage in well-structured dyadic interactions from the first few months of life (Cohn & Tronick, 1987). By the end of the first year, infants engage in triadic interactions, in which they share attention on objects with an adult, following the adult's gaze to the object, and directing the adult's attention via pointing and other communicative gestures (Bakeman & Adamson, 1984; Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Bruner, 1983). A number of researchers have argued that these rich interactions are evidence that infants appreciate others' intentions (Bretherton, 1991; Tomasello, 1995). However, other researchers have pointed out problems with assuming that infants' social responses are direct evidence for their intentional understanding.

To start, infants' social responses may lead to overestimation of their social knowledge because they can often be explained by low-level factors, reinforcement learning, or by adults' management of infants' actions. For example, infants' spontaneous tendency to follow others' gaze shifts has sometimes been argued to reflect tacit knowledge about others' attentional states (i.e., infants are assumed to follow gaze because they know the other person is looking at something). However, as Moore and Corkum (1994) pointed out, infants might follow gaze based on a history of reinforcement for doing so, or based on lower level attentional mechanisms (such as orienting to the movement of the face and/or eyes), without yet understanding that others can be linked to objects via attention (see also Woodward, 2003b, 2005a).

On the other hand, reliance on spontaneous social responses as evidence can also lead to underestimation of infants' intentional action knowledge depending on the criteria used and the complexity of the social responses involved. As one example, Tomasello and his colleagues have developed innovative laboratory procedures for measuring infants' action understanding via their responses to social partners. These studies get around many of the problems involved in reasoning from naturalistic observations, and therefore they support stronger conclusions concerning infants' intentional action knowledge. But the cost of this rigor is that the requisite responses are quite demanding. To illustrate, in one study (Behne, Carpenter, Call, & Tomasello, 2005) infants interacted with an experimenter who repeatedly handed over small toys. One some trials, the experimenter failed to deliver the toy. In some cases, the failed delivery was accompanied by evidence that the experimenter had tried to deliver the toy, but failed. In other cases, the experimenter acted as if she intended to withhold the toy in a teasing manner. Infants 12 months of age and older responded in clearly distinct ways to "unable" versus "unwilling" trials, producing communicative behaviors that suggested annoyance or impatience on the latter but not the former trials. Six-month-old infants did not respond differently on these two kinds trials, leading the authors to suggest that they were unable to discern the experimenter's intentions. However, this failure may reflect the complexity of the testing context and the requisite social responses. Six-month olds do not typically participate in toy exchange games, nor do they produce communicative gestures, each critical elements of the experimental procedure.

As these two kinds of problems illustrate, because spontaneous social behavior is driven by many factors, it often cannot support clear conclusions concerning infants' underlying cognitive processes (see Brune & Woodward, 2007, for a discussion). Over the past decade, researchers have developed tools for more precisely isolating infants' analysis of others' actions. One of the first tools recruited for this purpose was the visual habituation paradigm. This method recruits a minimally demanding response (looking) that is well within the capacity of very young infants and also appropriate for older infants. The logic behind this method is simple: When shown the same event repeatedly, infants attend to it less and less, showing a habituation response. Once infants have habituated, they show recovery (increased visual attention) to events that differ from the habituation event, but only if they detect the difference and find it novel. Thus, infants' patterns of recovery can reveal the structure of their event representations. Critically, for our current focus, we can use this paradigm to ask whether infants show a selective novelty response to changes in the relational aspects of intentional action.

2.1. Instrumental Actions as Goal Directed

Adults interpret even concrete actions not as purely physical motions through space but rather as directed at particular objects or outcomes, that is, in terms of intentional relations. The action depicted in Figure 1 (a person reaches toward and grasps a toy), is a case in point. On one analysis, this is a simple, concrete movement through space. But adults see it 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.

To test whether infants represent the relational structure of events like this one, we recruited the visual habituation paradigm. Infants first viewed an event, like the one in Figure 1, repeatedly until they had habituated to it. Then, the objects' positions were reversed and infants viewed test events which either disrupted the spatial properties of the reach while maintaining the relation between the actor and the object she grasped (*new-side trials*) or

Figure 1 **Stimuli from visual habituation studies of infants' analysis of reaching actions as goal directed.**

maintained the spatial properties of the reach while disrupting the relation between the actor and the object (*new-goal trials*). Infants as young as 5 months of age showed a stronger novelty response (i.e., longer looking) on new-goal trials than on new-side trials (Guajardo & Woodward, 2004; Woodward, 1998, 1999).

A second way to examine infants' novelty response is to compare their attention on the test trials to their attention at the end of the habituation phase. Infants might detect the novelty in both kinds of test trials, and thus recover attention relative to the end of habituation, even if they look longer overall at one kind of test trial than another. Interestingly, in these studies, infants typically show recovery of attention on new-goal trials but not on new-side trials. Even though new-side trials present infants with several changes (the toys have been moved, the arm takes a new path and arrives at a new location), infants do not respond to these events as if they were different from the habituation event. This pattern of response suggests that infants represent these actions in terms of the relation between the agent and her goal. When the relation is disrupted, they find the resulting event novel. When the agent-goal relation is preserved, even when other aspects of the event have changed, infants do not show a strong novelty response.

This selective response to goal changes has been replicated in a number of infant laboratories (Biro & Leslie, 2007; Brandone & Wellman, 2009;

Sodian & Thoermer, 2004; Wellman & Phillips, 2001). Critically, infants do not show this response for all events in which one object moves toward and contacts another. They do not respond selectively to ''goal'' changes when the moving entity is not readily identified as an agent (Hofer, Hauf, & Aschersleben, 2005; Woodward, 1998), or when the action is ambiguous (Woodward, 1999; Woodward & Guajardo, 2002). In these cases, infants respond equally to the change in ''goal'' and the change in the patterns of movement. Thus, infants' response to goal-directed actions seems not to derive from general properties of the event, such as the way the moving entity entrains attention to the object or the repeated spatial association between the moving entity and the object. Instead, infants' selective response on new-goal trials seems to reflect knowledge about goal-directed action *per se*.

Further evidence for this conclusion comes from studies in which infants are presented with novel or ambiguous agents, for example, a mechanical claw. Infants do not spontaneously respond to the movements of an inanimate object as if they were goal directed; however, infants' tendency to view these events as goal directed can be shifted by contextual cues indicating the animacy of the agent or goal directedness of the action (Biro & Leslie, 2007; Hofer et al., 2005; Luo & Baillargeon, 2005; Shimizu & Johnson, 2004). To illustrate, Hofer et al. found that 9-month-old infants did not view a mechanical claw's actions on an object as goal directed. However, when infants first saw that the claw was manipulated by a person, they subsequently responded to the claw events as if they were goal directed, that is, showing selective attention to changes in the claw-goal relation as compared to changes in the claw's movements.

The findings from these visual habituation experiments led us to ask whether infants' sensitivity to action goals is expressed in behaviors beyond their patterns of visual attention. In other domains of infant cognition, habituation experiments have sometimes revealed knowledge that is strikingly absent when assessed in infants' overt actions. The most well-known example of this kind of dissociation is the case of object permanence. Young infants show evidence of representing hidden objects in looking time experiments many months before they can successfully search for a hidden object (Baillargeon, 1995; Spelke, Breinlinger, Macomber, & Jacobson, 1992).

Is infants' action knowledge similarly limited early in the first year? Younger infants' failures on measures of complex social responses suggest it might be. However, we reasoned that a simpler task might be more successful at revealing young infants' action knowledge. Based on findings with older infants, we predicted that younger infants would selectively imitate the goal of an observed action, so long as the response demands were low and the event was familiar to them. We presented 7-month-old infants with an experimenter who modeled a goal-directed reach toward one of two small toys. Then, infants were given a chance to choose between the toys. In this condition, infants systematically chose the toy that had been the experimenter's goal (Hamlin, Hallinan, & Woodward, 2008). However, when infants saw the adult direct an ambiguous action toward the toy (Hamlin et al.) or saw an inanimate object approach the toy (Mahajan & Woodward, under review), they chose randomly when given the choice between them. Even though all of these kinds of movements led infants to attend to the toy, only one, the human reach, was seen as goal directed, and this interpretation drove infants' responses.

2.2. Higher Order Instrumental Goals

Instrumental goals can be perceived at varying levels of analysis, Goals structure individual actions, and these individual actions can in turn be assembled in service of more abstract goals. For example, in the event depicted in Figure 2, a woman grasps a cloth, and then pulls it toward herself to reach the toy it supports. At one level, we can encode the goals that structure each action (grasping the cloth, grasping the toy), and we also understand these actions as part of a higher order plan (obtaining the toy). Thus, we understand the woman's actions on the cloth as not simply directed at the cloth itself, but ultimately at the toy.

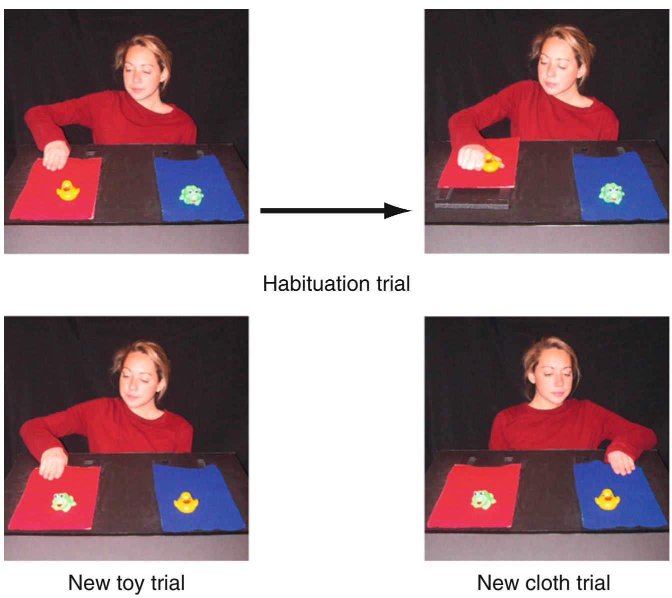

Figure 2 Stimuli from visual habituation studies of infants' analysis of means-end goal structure.

By the end of the first year of life, infants detect higher order goals such as this one. In one study (Sommerville & Woodward, 2005) infants were habituated to the event depicted in Figure 2—a woman pulled one of two cloths to obtain the toy it supported. The question of interest was whether infants interpreted the adult's grasp of the cloth as directed at the cloth itself or instead at the toy. To address this question, after habituation the location of the toys was reversed, and infants saw the adult grasp the same cloth as during habituation, which now held a new toy (new-goal trials) or grasp the other cloth, which now held the toy that had been the goal during habituation (new-cloth trials). Twelve-month-old infants showed a greater novelty response on new-goal trials than new-cloth trials, indicating that they interpreted the reach to the cloth as directed at the toy. Like adults, infants are based their analysis of the actor's goals on the causal relations between them—the grasp of the cloth can be interpreted as directed at getting the toy because it plays a causal role in obtaining the toy (by bringing the toy within reach). Disrupting the causal relation disrupted infants' encoding of the higher order goal: When another group of infants viewed events like those in Figure 2 except that the toy sat to the side of the cloth rather than on it, they did not respond selectively on new-toy trials.

These findings have been replicated using other kinds of means-end sequences, indicating that the ability to analyze higher order goals is relatively general by the end of the first year of life (Sommerville, Hildebrand, & Crane, 2008; Woodward & Sommerville, 2000; see also Gergely & Csibra, 2003). Further, as was the case for reaching actions, infants' analysis of higher order goals is expressed in their imitative behavior as well as their looking times (Hallinan, Hamlin, DeNale, & Woodward, 2007). Taken together, these findings indicate that, by the end of the first year, infants represent plans as independent of the particular actions that are assembled to complete them.

2.3. Attention as Object Directed

Adults represent not only the physical relations between agents and the objects on which they act, but also the invisible relation between an agent and the object of his or her attention. By the end of the first year of life, infants represent this invisible connection. In one study, we showed 7-, 9- and 12-month-old infants events in which an experimenter turned to look at a toy, as shown in Figure 3 (Woodward, 2003a). Infants at all ages reliably followed the person's gaze, turning to look at the same toy she did. Our question was whether infants not only followed gaze, but also understood the relation between the experimenter and the object at which her gaze was directed. To address this question, we used the habituation paradigm developed in earlier studies. Following habituation to one looking event, the objects' positions were reversed and infants viewed *new-goal* test trials

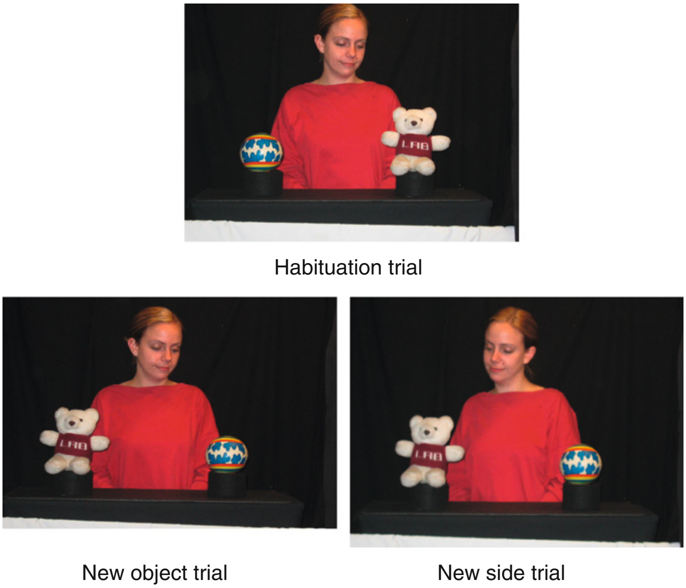

Figure 3 **Stimuli from visual habituation studies of infants' analysis of attention as object directed.**

which disrupted the object to which the experimenter directed gaze and *new-side* test trials which changed the experimenter's physical motions while maintaining the same object as the target of attention. The 7- and 9-month-old infants did not respond to the change in agent-object relation. In fact, they did not recover attention on either kind of test event. Despite the fact that they had followed the experimenter's gaze to the object, infants at these ages seemed not to represent the relation between the experimenter and object. Thus, infants' social responses, in this case gaze-following, do not always express underlying knowledge about the intentional actions of social partners. In contrast, 12-month olds not only followed the experimenter's gaze, they also responded systematically to the change in agent-object relation by looking longer on new-goal than new-side trials (see also Johnson, Ok, & Luo, 2007; Woodward & Guajardo, 2002).

By 12 months, infants also relate attention to other aspects of a person's intentional actions. Phillips, Wellman, and Spelke (2002) found that 12-month-old infants use gaze direction to predict a person's next actions. Infants at this age expect that a person will reach toward the object at which she has just looked, and detect a violation when she reaches for an object she has not attended to (see also Sodian & Thoermer, 2004). Luo and Baillargeon (2007) found that 12-month-old infants interpret a person's predispositions to act based on what she can see. When an actor chose between two toys with full visual access to both, infants assumed she would continue to reach for that object when given the choice again. However, when the actor at first had no visual access to the unchosen toy, infants did not assume she would choose the target again when given a choice between the two toys.

Onishi and Baillargeon (2005) demonstrated that slightly older infants, 15-month olds, can track a person's attention to an object across displacements, and use this information to predict her next actions (see also Southgate, Senju, & Csibra, 2007; Surian, Caldi, & Sperber, 2007). Because infants assume the agent will return to the place she last saw the object, even when the object has been secretly removed from the location, these findings have been suggested to be evidence for "false belief" reasoning in infants. This interpretation has been challenged (Perner & Ruffman, 2005). Even so, at the very least this work shows that infants are skilled at integrating information about a person's attention to and actions on objects.

These findings highlight the relational nature of infants' action analysis. Infants encode not only the relations implied by individual actions but also relations among these different kinds of intentional relations. The preponderance of evidence for this integration of intentional relations comes from studies of infants 12 months of age or older. However, in a recent study, Luo and Johnson (2009) found that 6-month-old infants condition their action predictions on the agent's prior perceptual access to the objects, as in the Luo and Baillargeon (2007) study. In addition to indicating that the ability to integrate information about intentional relations emerges early, these findings also suggest that infants can encode attentional relations at younger ages than previous findings suggested, perhaps because attentional relations are made more salient when they are accompanied by other object-directed actions (see also Johnson et al., 2007).

2.4. Personal Nature of Goals

For adults, a central organizing principle is the continuity of goals within individual people. Indeed, at the heart of our conceptions of both intentional action and persons is the idea that individual people carry with them goals and behavioral propensities. Adults readily attribute to others enduring personality traits, emotional states, and behavioral propensities based on only "thin slices" of observed behavior (Ambady & Rosenthal, 1992). This ability yields the perception of coherent persons and underlies our ability to interpret and predict others' actions over various time scales, including short-term goals that guide actions in the moment as well as longer term preferences and predispositions. Researchers have long assumed that socioemotional processes such as attachment and stranger anxiety depend on infants' cognitive representations of individuals and their psychological or behavioral propensities (see Thompson, 1998 for a review).

However, until recently, there was little direct evidence concerning whether and when infants track goals as a function of the individual agent.

The findings reviewed so far provide strong evidence that infants represent actions as goal directed, but they do not resolve the issue of whether infants understand goals as attributes of individuals. In principle, infants could encode an event as goal directed without linking this analysis to a particular person. In the first months of life, infants can distinguish between individual faces (Slater & Quinn, 2001) and voices (DeCasper & Fifer, 1980), and they are able to learn about novel face–voice relations (Brookes et al., 2001). These abilities provide the basis for, but are distinct from the ability to conceptualize a person with enduring goals. Do infants link perceptual representations of the individual agent with their analysis of the agent's goal?

We recruited the habituation paradigm developed in our prior work to address this question (Buresh & Woodward, 2007; Henderson & Woodward, under review). We presented 9- and 12-month-old infants with reaching events, like the ones described earlier, except that the experimenter's face and upper body were visible. Infants were first introduced to two experimenters, one male and one female. Then infants in the *two-experimenter* condition saw one-experimenter produce the habituation events, and the other during the test phase. We reasoned that if infants understand goals as attributes of individuals, then they should not generalize goal information from the first experimenter to the second. Knowing what person A intends should provide little insight into person B's goals. A second group of infants saw the same experimenter throughout the procedure (the *one-experimenter condition*). This group showed the same pattern of responding found in earlier experiments—a strong novelty response on goal change trials but not on path change trials. In contrast, infants in the two-experimenter condition did not respond systematically on test trials.

This finding suggested that infants had restricted the goal information to the first experimenter. However, to be sure of this, we first needed to address the possibility that infants' failure to respond systematically in two-experimenter condition was due to the novelty of the second experimenter detracting from infants' ability to attend to her actions. First, we coded and compared infants' attentiveness to the events in the one- and two-experimenter conditions. Infants in the two conditions were equally attentive to the test events overall, and equally attentive to the experimenter's hands and face, suggesting that infants in the two conditions had equal opportunity to encode the relevant parts of the event.

Next we conducted a control study in which infants viewed different experimenters during habituation and test, but this time in the context of an action that should generalize across individuals, the use of a conventional label for one of the objects. The events were identical to those in the two-experimenter condition except that when the experimenters grasped the object, they uttered a label for it ("A mido."). Under these conditions, infants generalized the information provided by the first experimenter to the actions of the second. They looked longer on goal change trials than side change trials. Thus, infants were able to generalize information across agents when it was appropriate to do so. Therefore, their restriction of goal information in the first study was not likely due to the demands on attention and information processing posed by the introduction of the second actor. Our initial findings (Buresh & Woodward, 2007) revealed these patterns most strongly at 12 months. In recent studies (Henderson & Woodward, under review), we have confirmed the same results in 9-month-old infants. Taken together, then, these findings indicate that infants, like adults, use the individual person as the unit of analysis for tracking action goals.

These results converge with emerging findings using different methodologies that may tap similar reasoning in infants. A critical aspect of dispositional understanding in adults involves the recognition that actions stem not only from transitory goals, but rather reflect enduring preferences or dispositions for object, people and activities. Sommerville and Crane (under review) investigated the circumstances under which 9.5-month-old infants view goals as stemming from enduring personal preferences for particular objects. Using a variant of Woodward's (1998) initial paradigm, infants saw habituation trials in which an actor repeatedly selected one of two toys. The actor's toy pursuit was accompanied by either a general remark ("Look. Wow!") or an explicit preference statement about the pursued object ("I like frogs"). Infants next received test trials in which the positions of the toys were reversed and the actor alternated pursuing a new-goal object and the old-goal object. Critically, to investigate whether infants viewed the initial object selection as reflecting an enduring preference, these test trials took place in a different room than the habituation trials. Infants in the explicit preference statement condition, but not the general remark condition, looked longer to the new-goal test events than the old-goal test events. Performance at an individual level was linked to infants' reported language comprehension. A follow-up condition revealed that whereas the preference statement facilitated goal transfer across contexts, it did not lead infants to generalize goals to other individuals. Thus, these findings suggest that, at least under certain circumstances, infants at 9.5 months assume that an individual's action reflects enduring preferences for or dispositions toward particular objects. A critical question for future research concerns the role of language in infants' understanding of preferences as enduring across time and space.

Kuhlmeier, Wynn, and Bloom (2003) tested whether infants would infer stable dispositions in agents shown in an animated film. They showed 12-month-old infants events in which three different geometric shapes (A, B, and C) moved as if they were animate agents. Agent A attempted to climb a steep hill. A's progress was helped by B, who pushed A up the hill, and hindered by C, who pushed A down again. Kuhlmeier and colleagues then tested whether infants would use these events to infer A's subsequent dispositions to act with respect to B and C by showing them test events in which A spontaneously approached either B or C. Infants looked longer when A approached the hinderer, C, than when A approached the helper, B. In later studies, Hamlin, Wynn, and Bloom (2007) obtained the same result in 9-month-old infants. Thus, like our findings, these results suggest that by 9 months, infants infer relatively stable (at least in the short term) goals or dispositions in individual agents.

Results from all three laboratories suggest that infants younger than 9 months may not readily attribute goals or dispositions to individuals. Hamlin et al. (2007) also tested 6-month-old infants and found that they did not generate predictions about A's interactions with B and C, although infants at this age did distinguish between B and C in other ways. In unpublished work (Sootsman Buresh & Woodward, 2005), our group found that unlike 9-month-olds, 8-month-old infants freely generalized goal information from the first experimenter to the second. Surprisingly, they did this even though they readily encoded the goal structure of the events and robustly detected the perceptual differences between the two people. Similarly, Blumenthal and Sommerville (in preparation) found that 8-month-old infants do not extend an individual's goals across contexts even under the most supportive contexts (in the presence of an explicit preference statement). It is not yet known whether these failures at younger ages reflect a general lack of insight into the individual and enduring nature of goals, or instead an inability to integrate the relevant aspects of information from the experimental events (e.g., the actor's face, her manual actions, and goal). This issue awaits further investigation.

2.5. Mental State Content of Intentional Relations

To summarize the conclusions to this point, when infants watch people act, they see more than bodies in motion; they see agents whose actions are structured by intentional relations. The actions of social partners attract and direct infants' attention, but infants do more than simply follow actions; they analyze their relational structure.

These findings leave open the question of how much infants understand about the psychological correlates of intentional relations. For adults, intentional relations are connected to, and explained by, a rich web of folk psychological knowledge. Adults have conceptions of mental states, including desires, perceptions, and intention, that explain the relations between agents and objects. It is possible, however, that infants represent intentional relations in terms of how actions are structured with respect to goal objects and objects of attention without reference to the mental processes that drive actions (see Gergely & Csibra, 2003; Woodward, 2005a). The absence of linguistic evidence from infants makes this issue particularly difficult to resolve.

Nevertheless, the evidence just reviewed suggests that by 9 to 12 months, if not before, infants understand something about the inner correlates of observable actions. Mature folk psychology represents mental states as existing independent of immediate physical actions or connections, as interacting with one another to influence subsequent actions, as residing within the individual agent. Infants' action analysis reflects these properties of mental states. Infants represent the abstract relation implied by acts of attention, and they represent higher order goals as distinct from particular, physical connections, seeing them instead as more abstract plans that organize concrete actions. Infants also engage in reasoning about the relations among different kinds of intentional relations, for example, in conditioning action predictions based on a person's prior focus of attention. Finally, as just summarized, infants understand goals not simply as properties of events, but as specific to the agent who acts and enduring across contexts. Thus although it is unlikely that infants understand others' mental lives in all the ways that adults do, infants understand intentional relations as existing independent of particular concrete actions, as interacting with one another, as residing within the individual and persisting across time and space. Each of these is part of what it means to understand intentional relations in psychological terms.

2.6. Collaborative Actions and Shared Goals

To this point we have considered infants' analysis of goals at the level of individual agents. Discerning individual goals, plans, and states of attention is critical to interacting with and learning from social partners. But if infants only represented individual intentional relations, they would miss much of the informative structure in the social world. Humans have a unique capacity to work together to achieve mutual goals, and much of the structure in the social world involves collaborative activity of this sort (Tomasello, Carpenter, Call, Behne, & Moll, 2005). In collaborative interactions, two (or more) people perform complementary actions to achieve a shared goal. Collaborations support the creation of concrete products (e.g., two people work together to make dinner or build a fence) and the attainment of abstract goals (e.g., a teacher and students cooperate as the class masters new material, members of a community adhere to conventional rules or roles that permit the attainment of social goals). The ability to represent collaborative goals is thus critical not only for making sense of others' actions in the moment, but also, ultimately, for understanding the more abstract goals that structure participation in social and cultural communities (Figure 4).

Figure 4 Stimuli from visual habituation studies of infants' analysis of collaborative actions.

Infants engage in interactions that can be described as collaborative during the first year of life. They participate in well-structured feeding routines (Duncan & Farley, 1990), communicative exchanges (Bates et al., 1979; Bruner, 1983), and cooperative games (Hubley & Trevarthen, 1979; Ross & Lollis, 1987). However, it is not always clear from these observations whether infants represent the shared goal structure of these interactions. An infant who performs the right action at the appropriate time in a routine (e.g., opening her mouth to receive food or taking her turn in a game of stack and topple) may do so based on the local contingencies of the routine rather than on a full understanding of the collaboration.

We have begun to seek clearer evidence concerning infants' understanding of collaborative interactions—asking whether 14-month-old infants represent the complementary actions of two individuals as being directed toward the same goal (Henderson & Woodward, under review). Using the visual habituation paradigm, we showed infants sequences in which one experimenter opened a box and held it open as a second experimenter reached inside to retrieve a toy. The experimenters exchanged smiling looks and nods expressing their mutual satisfaction with the outcome. Our question was how infants understood the actions of the first experimenter. Do infants conceive of this experimenter's goal as the box (the only object that she touched) or do they interpret her actions as enabling the attainment of the toy by the second experimenter? To address this question, we showed infants test events in which the first actor reached toward either the box or the toy. If infants interpreted her goal as the box, then the reach to the toy should seem novel to them. If, in contrast, infants interpreted her goal as the toy, then the reach to the box should seem novel, even though this was the object she had acted on throughout the habituation phase. Fourteen-month-old infants looked longer on box trials than toy trials, indicating that they had interpreted the first actor's goal as the toy, not the box.

Understanding collaboration involves not just detecting shared goals, but also the understanding that the actions of the participants are jointly necessary for the attainment of the goal. Teammates who work together to win a soccer match have collaborated, but the fans cheering from the sidelines have not (unless their cheering has so boosted the spirits of the players that it enables them to press on for the final goal). To assess whether infants engaged in this kind of analysis, we showed a second group of infants sequences identical to those in the first condition except that the toy sat next to, rather than inside, the box. The first experimenter opened the (empty) box, the second experimenter grasped the toy, and they exchanged the same satisfied looks and nods as in the first condition. In this case, however, the first experimenter's actions played no causal role in the attainment of the toy. Infants recognized this disruption—they did not infer that the first experimenter's goal was the toy in this condition.

Taken together, these findings indicate that, by 14 months, infants understand collaborative interactions as involving complementary actions in service of attaining a shared goal, at least in cases of relatively simple, concrete collaborative activities. This ability would allow infants initial access to the goal structure inherent in many social interactions, and thus lay the foundation for learning from and participating in more abstract forms of social collaboration. Our findings at 14 months raise a number of questions. First, how early can infants' sensitivity to collaborative goals be traced? Further, questions remain concerning the kinds of collaborations infants can represent. Do they, for example, understand the collaborative nature of communicative interactions or other acts of socially motivated collaboration? Ongoing research in our laboratory has begun to investigate these issues.

2.7. Summary: Infants' Analysis of Intentional Relations

We began with the observation that adult social perception is grounded in the analysis of human actions in terms of intentional relations. The research summarized so far provides strong evidence that the elements of this social worldview emerge very early in human ontogeny. Infants represent human actions in terms of the relation between agent and object. They see these relations in concrete actions on real objects, in higher order plans that structure sequences of actions, and in acts of attention. Like adults, infants see the person as the organizational unit for intentional relations—they track intentional relations as a function of the person who acts. Further, like adults, infants are not limited to reasoning about the goals of individual people—they can also recover the shared goal structure of collaborative activities.

These elements of social perception emerge by the end of the first year of life, a time when infants have very little, if any, language, and without explicit instruction. They are in place in time to focus infants' social learning in the second year of life. Because infants see others' actions in terms of intentional relations, they are able to glean information from others actions about word meanings, culturally specified forms of behavior, functional properties of objects, and safety and danger. Infants' intention-reading clearly sets the stage for future learning. In Section 3, we consider the epigenetic roots of this ability. What processes give rise to infants' intention-reading?

3. Developmental Origins of Intention-Reading

Our review up to this point has highlighted two facts that any developmental account must explain: The perception of intentional relations is spontaneous and universal in adults, and it emerges during infancy, before children possess the explicit folk psychological knowledge that emerges in early childhood. Further, because intention-reading is so critical for human social functioning and the development of key human abilities, such as language and culture, it is reasonable to assume that it has been shaped by natural selection.

These considerations have led some developmental scientists to stress the role of innate core knowledge in explaining the origins of intention-reading. Several variants of this general proposal have been formulated, each positing that the universality and early emergence of intention-reading is explained by the existence of innate core knowledge about intentions (Biro & Leslie, 2007; Gergely & Csibra, 2003; Luo & Baillargeon, 2005; Premack, 1990). Under these proposals, experience may play a role in shaping the application of the core knowledge to real world cases, but the core representation of intention exists independent of experience. Nature's response to the importance of intention-reading for human survival, under these views, was to build in the core architecture.

Nature could have responded differently. The early emergence and universality of an ability may also reflect the effects of early and universally available experience. Indeed, it is common for developmental systems to recruit information that is reliably present in the environment. This is true not only for learning based on individually variable experiences (like learning to read or play chess), but also for the development of species-typical abilities that are critical to survival (Greenough, Black, & Wallace, 1987; Johnson, 2005; Marler, 1991). For example, bird song, navigation, and social imprinting in various species all depend on information from the environment to develop typically (Gallistel, Brown, Carey, Gelman, & Keil, 1991; Gottlieb, 1991; Marler, 1991). Often, the relevant experiences are reliably present because they are produced by the developing organism itself. Gottlieb's elegant work on imprinting in ducklings is one example: for some species, the duckling's response to the mother duck's call after hatching depends on prenatal exposure to their own calls, produced in the air sac of the egg. Similarly, species-typical human intention-reading abilities may derive important structure from experience, and perhaps experience produced by infants themselves.

Of course development always involves the interplay of inherent structure in the developing organism and structure in the environment. Uncovering developmental mechanisms requires specifying the relative contributions of each of these at different points in development. With this goal in mind, we have begun to explore the extent to which early experience influences infants' intention-reading. Does intention-reading emerge independent of experience in infants? Or, is it shaped by infants' experiences?

3.1. Developmental Relations Between Producing and Perceiving Goal-Directed Action

In considering these questions, we have focused on one potentially informative set of experiences in infants' lives—namely, their own experiences as intentional agents. As in the case of Gottlieb's ducklings, self-produced actions provide reliable input for development. But beyond being reliably present, infants' own actions are potentially structurally informative for intention-reading because infants' actions are structured with respect to external goals from birth (Hofsten, 2004). During the first year, infants undergo several revolutions in their ability to produce coordinated goal-directed actions. One milestone occurs at around 5 months of age, when infants begin to robustly produce smooth object-directed reaches (Bertenthal & Clifton, 1998; Clearfield & Thelen, 2001). A second occurs at around 9 months of age, when infants begin to be able to organize means-end action sequences in service of higher order goals (Piaget, 1953; Willatts, 1999). These skilled actions are the product of extended months of practice during which infants' actions become progressively more organized with respect to goals. We have begun to investigate the possibility that infants' intention-reading is shaped by these developments in their own actions. If the systems that guide action control are accessible to the systems that perceive action, then as infants come to control goal-directed actions such as reaching or tool use, these developments could provide information to structure infants' perception of others' actions.

It has long been hypothesized that first-person experience provides unique insight into others' intentions (Barresi & Moore, 1996; Gallese, 2001; Meltzoff, 2007; Tomasello, 1999). Recent work from our laboratories has provided growing evidence in support of this hypothesis. To start, developments in infants' own goal-directed actions correlate with their tendency to view others' actions as goal directed. At 10 months, infants who are skilled at producing means-end sequences represent the means-end structure of others' actions, but those who are less skilled do not

(Sommerville & Woodward, 2005). Similarly, at 9 months, infants who produce object-directed points understand others' points as object directed; infants who do not yet point do not (Brune & Woodward, 2007; Woodward & Guajardo, 2002). These correlational findings indicate a link between infants' actions and their action perception, but they cannot specify the causal relations that give rise to the correlation. To get a clearer view of the potential effects of acting on action perception, we have turned to intervention studies in which we support infants' ability to engage in a new goal-directed action and then assess the effects of this engagement on their subsequent perception of others' goal-directed actions.

3.1.1. Learning to Reach for Objects

In our first study to address this issue (Sommerville, Woodward, & Needham, 2005), we intervened with infants who are very limited in their perception and production of goal-directed actions—3-month olds. In our pilot habituation studies, infants younger than 4–5 months of age had never shown systematic responding to goal changes, despite our best efforts to make the procedure as simple as possible. In addition, 3-month-old infants are generally not able to produce coordinated object-directed reaches (Bertenthal & Clifton, 1998; Clearfield & Thelen, 2001). However, Needham, Barrett, and Peterman (2002) found that infants at this age can learn to apprehend objects by swiping at them while wearing Velcro-covered "sticky mittens," as depicted in the first photo in Figure 5. After discovering that the mittens can apprehend objects, infants begin to act on objects in more organized ways, looking at the object while aiming swipes toward it.

To assess whether mittens experience affects infants' perception of others' actions, we gave one group of infants practice with sticky mittens and then tested them in a habituation paradigm like the one depicted in Figure 1. We wanted to maximize infants' ability to detect the similarity

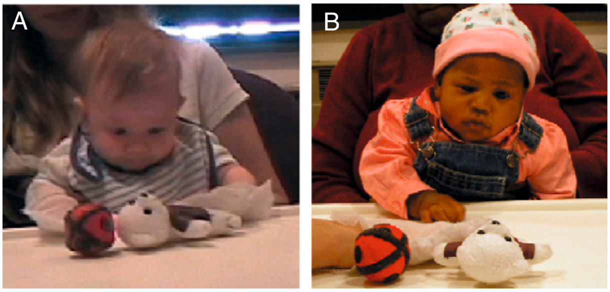

Figure 5 A 3-month-old infant uses "sticky mittens" to apprehend toys in the active condition (A); another 3-month-old infant watches mittened actions in the observation condition (B).

between their own actions and those in the habituation events, and so we used objects in the habituation events that were larger versions of the ones on which infants had acted and had the presenting experimenter wear an adult-sized mitten.

This procedure was a demanding one for such young infants. Given 3-month-old infants' limited attention spans, as well as their frequent need for naps and feedings, the training had to be very short in order for infants to be able to complete the subsequent habituation procedure. This meant that infants had only 3–5 min opportunity to use the mittens before the habituation paradigm began. Even given this limited amount of practice, mittens training had a powerful affect on infants' responses to the habituation events. Following mittens training, infants showed a marked increase in attention on new-goal as compared to new-side test trials, responding like older infants typically do in response to goal-directed actions. In contrast, a control group of infants, who viewed the habituation events without prior mittens experience, did not respond differentially to new-goal versus new-side test trials.

Although mittens experience increased infants' object-directed activities on average, there was also individual variation in infants' level of activity during the mittens training. This variability allowed us to investigate the aspects of the training experience that were critical for infants' response to the goal structure of the actions they observed in the habituation paradigm. In particular, we asked whether it was engagement in object-directed activity *per se*, independent of general visual familiarity with the mitten and toys that was critical. Our findings confirmed that it was the former, not the latter aspect of experience that mattered. The degree to which infants engaged in object-directed actions with the mittens (as indexed by coordinated manual and visual contact with the object) was strongly correlated with their subsequent selective response on new-goal trials. Infants' total visual engagement with the toys was not reliably correlated with their subsequent responses in the habituation paradigm.

These findings showed that infants' own object-directed actions influenced their subsequent perception of others' actions as goal directed, but there still remained a question about the nature of the information that their own actions provided. One possibility is that infants created for themselves a set of informative visual events. They saw their hands reach for, apprehend and move objects, and perhaps these regularities were sufficient to provide information about the relational nature of the actions. Indeed, Biro and Leslie (2007) have suggested that infants use these visual cues to identify goal-directed action. In this case, infants' learning from their own actions would be no different from their observational learning from others' actions. Alternatively, self-produced actions may provide unique information about action structure that could not be gleaned from observation alone. If action production systems provide structure for action perception, then we would predict that self-produced actions would have a unique effect on infants' action perception.

To investigate these issues, we next compared the effects of active mittens training to the effects of closely matched observational experience (Gerson & Woodward, under review). We first sought to replicate the prior effect of active experience on infants' action perception with a slightly larger sample than in the earlier study. As was the case in the first study, we found a tight correlation between infants' own object-directed actions with the mittens and their subsequent selective attention on new-goal compared to new-side trials. In this larger sample of infants we were also able to more closely analyze the nature of this correlation. We found that the function that related infants' reaching actions to their looking time preference was logarithmic rather than linear. This result suggested a threshold effect, such that a minimal level of experience was required to induce a systematic preference for new goal over new-side trials. Given the constraints of the experimental context, the required experience level was relatively low (infants needed to achieve 45 s of object-directed activity within the 3 min training phase). Even so, these findings suggest that a minimal level of expertise is needed to support infants' propensity to see observed actions as goal directed.

Because individual variation in active mittens experience was so closely tied to infants' looking time responses, we sought to obtain similar variation in infants' experience in the observational condition. To do this, we yoked each infant in the observation condition to an infant in the active condition. Each infant viewed an adult producing mittened actions according to a script generated from an infant in the active training condition. We coded infants' attention to the modeled actions on line and then again after the fact from video to ensure that they had attained the scripted level of observational experience.

The yoked design meant that infants in the two conditions received similar levels of experience on average, and also similar degrees of individual variation in experience. This allowed us to assess not only any group level effects of training, but also whether there were correlations or threshold effects in the observational condition, similar to those seen in the active condition. It seemed possible that observational experience could have similar, but less robust effects on infants' subsequent looking time responses. In this case, infants' degree of observational experience might correlate with their subsequent preference for new goal over new-side trials, even in the absence of a group level preference for new goal over new-side trials.

Our findings in this condition revealed none of the potential relations between infants' observational experience and their responses in the habituation paradigm. Neither infants as group nor infants with high levels of observational experience showed any reliable differences on test trials. Further, there was no indication of a correlation between the amount of observational experience infants received and their degree of preference for new goal over new-side trials.

These findings suggest that self-produced experience had a unique effect on young infants' perception of others' goal-directed actions. Indeed, it is possible that very young infants may only succeed in detecting action goals when they have the support of their own actions to do so. Three-month-old infants do not recover the goal structure of reaching events when tested in our visual habituation experiments without active experience (Sommerville et al., 2005), and the earliest reports of goal encoding in these kinds of paradigms in the absence of action interventions are in infants 5–6 months of age (Biro & Leslie, 2007; Brandone & Wellman, 2009; Wellman & Phillips, 2001; Woodward, 1998, 1999).

3.1.2. Learning to Organize Means-End Action Sequences

Self-produced actions strongly affect infants' earliest abilities to discern the goal structure of others' concrete actions. Toward the end of the first year both infants' actions and their analysis of others' actions become increasingly abstract. Infants begin to organize their own actions in means-end sequences, and they also begin to understand that others' actions can be organized as means to an end. To illustrate, as we described earlier, having been habituated to the cloth-pulling sequence at the top of Figure 2, 12-month-old infants looked longer on new-toy than new-cloth trials. They understood that the woman's actions on the cloth were directed not at the cloth itself, but rather at the toy that was drawn near by her actions on the cloth.

Do infants' own actions contribute to their ability to analyze others' higher order goals? Initial evidence on this issue came from a study in which we tested 10-month-old infants in the paradigm depicted in Figure 2 (Sommerville & Woodward, 2005). In contrast to 12-month-olds, 10-month-old infants showed no strong group tendency in their responses on the test trials, varying in their relative attention to new-cloth and new-toy trials. We also found variability in 10-month-olds' own actions when they were confronted with a cloth-pulling problem. Some infants were able to form well-organized solutions most of the time, pulling the cloth while attending to the toy, and grasping the toy when it came within reach. Other infants, in contrast, did this less often, instead straining toward the toy or becoming distracted by the cloth. The variation in infants' own actions correlated with their responses in the visual habituation paradigm: infants who produced more well-organized means-end solutions showed a stronger tendency to view the observed actions as directed at the toy, rather than the cloth.

Following from these findings, we next asked whether training to boost infants' means-end actions would lead to changes in their perception of others' means-end actions (Woodward, Mahajan, & Sommerville, in preparation). We tested 8-month-old infants, who are limited in their ability to organize means-end actions. One group of infants (*the active condition*) was presented with repeated opportunities to solve cloth-pulling problems, interspersed with a block of training trials in which the experimenter first demonstrated a solution and then immediately presented the same problem to the infant, as depicted in Figure 6. Infants benefited from this training. They spontaneously produced well-organized solutions only about a third of the time prior to training but produced well-organized solutions nearly two-thirds of the time on average by the end of the training trials.

After this training, infants' response to observed means-end actions was tested as described earlier and depicted in Figure 2. We found a strong correlation between infants' own actions and their responses to the observed actions: infants who produced high levels of well-organized solutions after the training phase looked reliably longer on new-toy than new-cloth trials, whereas infants who produced few well-organized solutions after training did not differentiate between the test trials. Thus, infants who benefited from training in their own actions also showed more advanced patterns of responding to the observed events.

To assess whether this effect on infants' action perception depended on self-produced experience, we tested a second group of infants who saw an adult perform well-organized cloth-pulling solutions repeatedly but did not get to act on the cloth or toy themselves (*the observation condition*). Infants in this condition were matched to individual infants in the active condition in terms of the total amount of time they spent engaged in or watching cloth-pulling actions. Because infants tended to take longer than the experimenter to produce a well-formed solution, infants in the observation condition viewed more exemplars of good solutions than did infants in the active condition. Further, infants were highly attentive to the training events, closely watching each phase of the action on the majority of trials. Even so, these infants did not benefit from what they saw: They did not respond systematically to the test events in the subsequent habituation procedure and there was no correlation between their degree of observational experience and their subsequent responses in the habituation paradigm.

Figure 6 An 8-month-old infant learns to engage in cloth-pulling actions.

Sommerville et al. (2008) obtained similar findings when they trained 10-month-old infants to use a cane to retrieve a distant toy. Using canes as tools is a novel and difficult task for infants at this age. On pretest trials, infants succeeded at retrieving the toy only about 30% of the time. Infants benefited from training and practice using the canes, however, succeeding close to 70% of the time following training. Critically, infants who received active training also responded systematically to observed cane-pulling actions in a paradigm analogous to the one depicted in Figure 2: Infants looked longer on new-toy trials than new-cane trials, and this effect was especially strong for those infants whose own actions were most well-organized after training. In contrast, infants who observed an experimenter using the cane under conditions matched to the active condition did not respond selectively to the means-end structure of the observed actions.

These two studies converge in indicating that self-produced actions continue to strongly influence infants' action analysis as both abilities become more abstract with development. Infants learned something from engaging in means-ends actions themselves that they were less able to learn from watching others act. Active and observational training each demonstrated the same sequence of actions (pull the cloth, then grasp the toy) and each provided infants with information about the physical structure of the problem (i.e., that the moving cloth would pull the toy within reach). But infants' own actions seem to have provided them with clearer evidence concerning the goals that organized the action sequence and made use of the physical properties of the problem.

While these findings with older infants are consistent with our results at 3 months, they seem inconsistent with other findings in 9- to 12-month-old infants. By these ages (and perhaps earlier) infants are able to analyze the goal structure of novel events in which one entity moves toward another, such as the movement of a claw or pointer toward an object (Biro & Leslie, 2007; Hofer et al., 2005), the movement of a self-propelled or socially interactive object toward another object (Luo & Baillargeon, 2005; Shimizu & Johnson, 2004), or the movement of one geometric shape toward another shape (Gergely et al., 1995; Kuhlmeier et al., 2003). While infants do not spontaneously view these events as goal directed, the presence of movement and/or featural cues that suggest agency can sometimes lead them to do so.

Given these findings, it may seem surprising that infants in the means-end training studies were unable to extract useful information from the experimenter's actions in the observation condition. The training events offered a rich set of cues to the experimenter's goals. She moved the toy toward herself, grasped it, and expressed pleasure at getting it. Why were infants not able to use these cues to infer the experimenter's higher order goal? In addressing this question, it is important to consider two differences between the training studies and the "novel agent" studies described above. First, the means-end training studies assess infants' understanding of higher order goals, in contrast to the novel agent studies, which generally involve single movements toward and contact with an object. Second, unlike the novel agents studies, the training studies required generalization of structural information from one event (in training) to another event (in the habituation paradigm). Given the design of these studies, infants must recruit information about the goal structure of the relevant actions, rather than specific information about the particular goal of the agent.

These considerations suggest two possible explanations for the apparent differences in infants' response in novel agent and training studies. First, agency cues may be sufficient to support the generalization of an existing action representation to a novel instance, but not sufficient to establish a new, more abstract action representation. The movements in many novel agent studies are sufficiently similar to grasping that, given supportive cues, infants may be able to extend their knowledge about grasping to these events when other cues strongly suggest the presence of an agent. But to make sense of the cloth-pulling events, infants must come to see a new level of action structure—the plans that organize individual actions in service of an ultimate goal. This new insight may require input from infants' own actions.

A second possibility is that infants even if infants are able to make sense of the experimenter's means-ends actions in the training context, they may be uncertain about how this structural information should be extended to new events. In the training studies, infants must take information from one event in the training context and use it to make sense of another event in the habituation booth. In comparison to observed events, infants' own actions may lead to more robust, flexible, or enduring structural representations that as a result are more readily generalized to new contexts.

These considerations highlight the question of whether infants' own actions provide insights into goal structure that they could never glean from observation alone, or instead simply provide more salient information than is generally provided by observation. The fact that infants sometimes respond to unusual events as goal directed has led several researchers to conclude that self-produced action cannot be the only source of goal representations, and that, instead, infants must be innately endowed with abstract goal concepts (Biro & Leslie, 2007; Gergely, Nadasdy, Csibra, & Biro, 1995; Luo & Baillargeon, 2005; Shimizu & Johnson, 2004). It is possible that multiple systems, including both self-produced actions and specialized perceptual modules, give rise to relational action representations (see Sommerville et al., 2008; Woodward, 2005a). However, it is also possible that infants' ability to discern goal structure in novel events depends on the analogical extension of action representations that they initially acquired in the context of their own actions (see Gerson & Woodward, in press). Further research is needed to resolve this question.

3.1.3. Learning About Attention

Do infants' own actions uniquely inform their understanding of the relation between an agent and the object of her attention? There is not yet conclusive evidence to answer this question, but two preliminary findings suggests they might. To start, we found correlations between infants' own pointing and their understanding of others points: At 9 months, infants who point at objects also understood others' points as object directed in a variant of our habituation paradigm (Brune & Woodward, 2007; Woodward & Guajardo, 2002). Because infants' earliest pointing behaviors seem egocentric, focused on highlighting objects of attention for themselves (Bates et al., 1979), we speculated that infants' production of points may highlight the attentional connections expressed in others' points (Woodward, 2005b). Of course without intervention studies, this hypothesis remains speculative.

A recent intervention study conducted by Meltzoff and Brooks (2008) provides further evidence that infants gain insight into others' states of attention from their own experience. In prior work (Brooks & Meltzoff, 2002), these researchers had investigated infants' responses to blindfolded adults in a gaze-following task. Older infants, 18-month olds, inhibited their spontaneous tendency to follow gaze when the adult wore a blindfold, suggesting they understood the impact of the blindfold on visual experience. In contrast, 12-month olds continued to follow the adult's gaze when she was blindfolded, suggesting they did not understand the implications of the blindfold. Meltzoff and Brooks gave 12-month-old infants experience wearing the blindfold themselves and found that with this experience, infants subsequently inhibited gaze-following when interacting with the blindfolded adult. Thus, self-produced experience with the blindfold seemed to give infants insight into the perceptual experience of others in the same situation. From these findings, however, it is not clear whether the self-produced nature of the experience was important. More research is needed to investigate this possibility.

3.2. How Does Acting Affect Action Perception?

Our findings show that infants' own actions provide critical information for understanding the actions of others. These results then raise the question of the mechanisms by which information from action production affects action perception. One possibility is that this process depends on forming an analogy between self and other. Analogical processes have been shown to be powerful mechanisms for extracting and generalizing knowledge in older children (Gentner & Medina, 1998), and it is plausible that these processes operate in the development of infants' action knowledge (Gerson & Woodward, in press). In their seminal analysis, Barresi and Moore (1996) hypothesized infants recruit their awareness of their own actions and intentional relations to create a structural analogy with the actions of others. This analogy would allow infants to infer that others' observable actions reflect the same kinds of underlying intentional relations that their own actions do. Under this account, collaborative action and joint attention between infants and caretakers would be critical for the development of intentional understanding because these interactions provide opportunities to align one's own intentional relations with those of others (see also Tomasello, 1999).

Alternatively, information from self-produced action may be extended to others more directly because overlapping neurocognitive representations serve to represent one's own and others' actions (Decety & Sommerville, 2003; Gallese & Goldman, 1998; Gerson & Woodward, in press; Meltzoff, 2007; Sommerville et al., 2005). To illustrate, Meltzoff's (2007) "Like me" framework begins with the supposition that there is a common cognitive representational format for self-produced and observed actions from birth. These *supramodal* representations reflect the common structure of actions of the self and actions of others, independent of the particular modalities by which these actions are perceived (e.g., kinesthetic vs visual). This shared representational format explains neonatal imitation and provides the foundation for constructing increasingly more abstract concepts of intention in oneself and others.

In support of this view, recent findings have documented the existence of shared neural representations for the perception and production of action (sometimes called mirror neurons or mirror systems) in adult nonhuman and human primates (Ferrari, Rozzi, & Fogassi, 2005; Fogassi et al., 2005; Grezes & Decety, 2001; Iacoboni et al., 2005; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). These mirror systems have properties that suggest they could be involved in the development of intention-reading (see Gerson & Woodward, in press). For one, mirror systems code goal directed or meaningful actions, rather than physical movements *per se*. Further, mirror systems are shaped by motor learning: adults with expertise in specialized actions like classical ballet dancing or using chopsticks show heightened mirror system responses when viewing these actions compared to nonexperts (Calvo-Merino, Grezes, Glaser, Passingham, & Haggard, 2006; Järveläinen, Schürmann, & Hari, 2004). These properties of mirror systems in adults suggest the possibility that during development, infants' emerging abilities to produce goal-directed actions could be recruited for the perception of others' goals.

There is increasing behavioral evidence compatible with the hypothesis that mirror representations exist in human infants, including neonatal imitation (Meltzoff & Moore, 1977), and much of the work summarized in this section of the chapter (see also Cannon & Woodward, in preparation; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Lepage & Theoret, 2007; Longo & Bertenthal, 2006). However, given the limited range of neuroimaging techniques that can currently be used to study infants, there is very little direct neural evidence for mirror systems in infants. One recent study from Southgate, Johnson, Osborne, Karoui, and Csibra (under review) sought evidence from infants for a pattern in EEG responses that had been discovered in adults. When adults plan a motor movement, there is disruption in alpha activity over motor cortex (also known as the mu-rhythm), and this same disruption occurs when adults view others' goal-directed actions (Muthukumaraswamy, Johnson, & McNair, 2004). Southgate and colleagues found a similar pattern of alpha suppression over motor cortex in 9-month-old infants when they viewed human goal-directed actions (reaching) but not when they viewed nonsensical human movements. These findings provide compelling neural evidence for mirror systems in infants and they point the way to future studies investigating the functional and developmental properties of these neural representations in infants (see also Shimada & Hiraki, 2006).

Even assuming a strong role for mirror systems in the development of intention-reading, we believe that conceptual learning mechanisms, including analogical mapping, also play an important role. These processes may explain how infants generalize action knowledge to novel or unusual events, and how they move from action-level knowledge to more explicit, folk theoretic knowledge (see Gerson & Woodward, in press). Furthermore, analogy has also been shown to contribute to developments in infants' own actions, for example, in providing a basis for generalizing means-end solutions to new problems (Chen, Sanchez, Polley, & Campbell, 1997), and this process, in turn, may broaden infants' ability to discern others' intentions.

3.3. Summary: Origins of Intention-Reading

Our findings indicate that human intention-reading is like many other species-typical abilities in that the ontogenetic processes that guarantee the emergence this ability recruit information that is readily available in the context of development. In this case, as in some others, the relevant information is produced by infants' own actions. As infants learn to organize their actions with respect to goal objects, they also gain new ways of perceiving structure in others' actions.

These findings raise a number of questions to focus future research. To start, how broadly do infants generalize information from their own actions? In these first studies, because our goal was to maximize the chances of findings effects of experience on intention-reading, we have been careful to match infants' own experience closely to the actions they view in the habituation in terms of the actions, tools and goal objects. However, if self-produced action is to contribute significantly to infants' intention-reading, infants must be able to generalize appropriately to a broader range of new events. Work underway in our laboratory investigates the question of when and how infants generalize action knowledge to new instances.

A second question is whether infants' own actions inform aspects of their intention-reading beyond the encoding of instrumental action goals (and perhaps attention). As we reviewed in the first part of this chapter, infants show early abilities to integrate information about different kinds of intentional relations, to link goals to individuals, and to recover the shared goal structure of collaborative actions. We do not yet know whether infants' own actions play a role in shaping these aspects of intention-reading, but it seems possible that they do. For example, infants' engagement in collaborative activities with adults toward the end of the first year of life may provide a context in which they can begin to discern shared goals.

Finally, these findings raise the question of how infants' emerging understanding of intentional relations interacts with other kinds of early social learning. It is clear that experience contributes to other aspects of infants' social knowledge, including the formation of social categories (Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002), the recognition of familiar faces and voices (DeCasper & Fifer, 1980), and the formation of expectations concerning the typical actions of caretakers (Johnson et al., 2007). The current findings raise the question of whether learning about these aspects of the social world depends differentially on self-produced versus observational experience. Further, they raise the question of how infants' emerging understanding of others' intentions interacts with learning about social categories, familiar social partners, and common patterns in the behavior of individuals or groups.

4. Conclusions

Classic theories of early cognitive development held that the everyday experience of the infant was a chaotic jumble of unstructured sensory input (Piaget, 1953). Infancy research over the past several decades has put this idea to rest with respect to infants' experience of the physical world (Baillargeon, 1995; Spelke et al., 1992). Only recently, however, have we begun to learn that infants are also skilled at seeing order in the social world.

The findings we have reviewed here support a number of conclusions concerning infants' intention-reading: Early in the first year, infants discern the relational structure of concrete, instrumental actions. By the end of the first year, infants are sensitive to higher order action goals, to relations between agents and the objects of their attention, and to relations among a person's focus of attention and his or her instrumental actions. Infants represent goals as specific to the individual person, but by early in the second year infants can also discern the shared goals that organize collaborative actions. In short, like adults, infants perceive a social world populated by agents whose actions embody intentional relations at varying levels of analysis.

When infancy researchers discover very early competencies this can invite the conclusion that these competencies are largely innately specified, arising independent of experience or learning. This conclusion was the first one drawn from findings of early competence in the physical domain (Spelke et al., 1992). More recent work has begun to uncover the role of early learning in infants' physical knowledge (Baillargeon, 2004; Johnson, Davidow, Hall-Haro, & Frank, 2008), and the field has taken a new interest in the role of experience in infant cognitive development more generally (Woodward & Needham, 2009).

Infants' intention-reading is fertile ground for this new perspective. As we elaborated in the second half of our review, mounting evidence indicates that experience contributes critically to infants' competence in the social domain. Specifically, infants' intention-reading is linked to developments in their own actions: As infants become able to organize actions with respect to goals, they also become able to see intentional structure in others' actions. Indeed, our findings suggest that self-produced experience provides infants with particularly strong, perhaps unique, insights into others' intentions.

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