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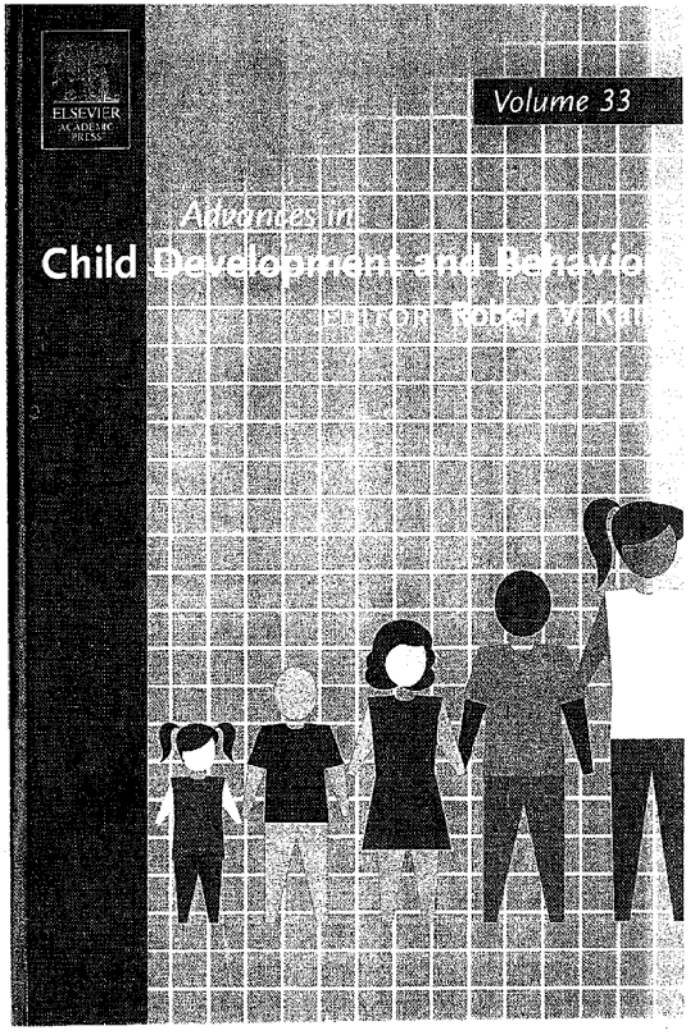

THE INFANT ORIGINS OF INTENTIONAL UNDERSTANDING

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I. Introduction

Children develop immersed in sea of human action. All around them, people traverse complex paths, attend to and act on objects, and interact with one another. Becoming a functional member of our species depends on being able to represent these actions not as purely physical motions through space, but rather as the manifestation of a person's psychological life. When this ability is seriously impaired, as is the case in autism, the effects on cognition and social life are pervasive and devastating (Baron-Cohen, 1995; Repacholi & Slaughter, 2003).

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Adults possess a system of knowledge sometimes termed "folk psychology" which explains observed behavior with reference to internal states such as beliefs, perceptions, emotions, and intentions. This system of knowledge takes years to fully emerge in human ontogeny (Wellman, 1992; Astington, 1993; Flavell & Miller, 1998). Even so, elements of intentional action knowledge are in place by the second year of life. Some of the strongest evidence for this point comes from studies of social learning.

To illustrate, imagine the following scene: preparing to head to the park, a man turns to his 1-year-old daughter and says "Now, where are your socks?" He proceeds to open a dresser drawer, peer inside, and pull out one item after another, tossing each aside with a sigh. Finally, he pulls out the socks and says "There we go". An astute child would understand her father's instrumental actions (opening the drawer, digging through the clothing), and attentional behaviors (peering into the drawer) as evidence of his intention (to obtain a particular item), and thus have a basis for understanding his subsequent actions. She would also be able to infer the meaning of the word "socks", even though she did not experience a direct pairing of the word and its referent. By 14–18 months, children do exactly this; that is, they use behavioral evidence of a speaker's attentional states and goals to interpret his or her subsequent actions, as well as his or her emotional expressions and the words that he or she utters (see Tomasello, 1999; Baldwin & Moses, 2001 for reviews). Moreover, when young children imitate the actions of adults they reproduce the apparent intention of the adult, not his or her exact motor patterns (Meltzoff, 1995; Carpenter, Akhtar, & Tomasello, 1998; Bellagamba & Tomasello, 1999; Gergely, Bekkering, & Kiraly, 2001; Hauf, Elsner, & Aschersleben, in press).

Thus, by the second year of life children's learning from social partners is mediated by an analysis of the intentional structure of action. By 18 months of age, children draw on a person's inferred goals, plans, and states of attention to glean new information, both about the person and about the environment. This conclusion highlights two important points. First, the ability to analyze the intentional structure of actions is foundational to social learning and cognitive development more generally. Therefore, it is critical to understand the developmental origins of this ability. Second, aspects of this foundational ability are present by 18 months of age. Therefore, the origins of these abilities should be sought still earlier in ontogeny. In this chapter, I review recent findings from studies that seek these origins. I begin by outlining what infants' seem to know about intentional action during the first year of life, and then I consider the question of how this knowledge originates.

II. What Infants Know About Action

A. CERTAIN ACTIONS ARE ORGANIZED BY THE RELATION BETWEEN AGENT AND GOAL

Mature observers interpret actions not as purely physical motions through space but rather as directed at particular objects or outcomes. This object-directedness is a perceived property of many intentional actions, both at the level of individual actions and at the level of sequences of action. This is evident in adults' event memory and narratives (Zacks & Tversky, 2001), and in children's responses to the actions of others (Bekkering, Wohlschlaeger, & Gattis, 2000). Even a simple, concrete action like the one depicted in Figure 1 is most readily described in terms of the relation between agent and goal ("She grasped the bear") rather than in terms of the strictly physical properties of the person's motion (e.g., "She moved her arm up and to the left"). We can perceive and represent the physical features of actions, of course. But, to adult eyes, the physical attributes are less central than the relation between the agent and his or her goal. A first question then, is whether, and under what conditions infants represent actions in terms of their goal structure.

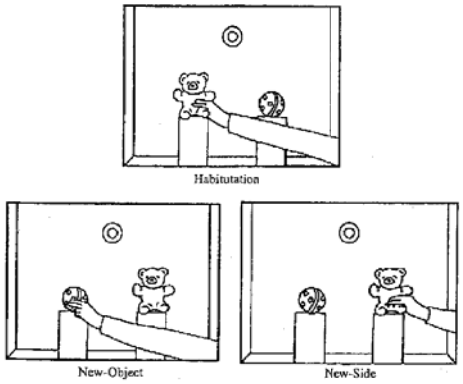

Fig. 1. Sample grasping events (based on Woodward, 1998).

The visual habituation paradigm offers a way to test whether infants, like adults, represent actions in terms of the relation between agent and object. The logic is to use infants' visual responses as evidence about the features they weight heavily in their mental representations of events. To illustrate, having habituated infants to one action, we present test events that either (1) vary the surface properties of the event while maintaining the relation between agent and object, or (2) preserve many of the surface properties while varying the relation between the agent and the object. Following full habituation, infants are predicted to look longer at stimuli that they perceive to be novel compared to the habituation stimulus. Therefore, longer looking on the latter trials than the former indicates that infants represented the original event primarily in terms of the relation between agent and object.

Our findings indicate that infants are sensitive to the goal-directed structure of one action, grasping, by the time they are 5–6 months of age (Woodward, 1998, 1999, 2003; Guajardo & Woodward, 2004). To illustrate, in one study (Woodward, 1998) infants were habituated to an event in which a person grasped one of two toys mounted on a stage (see Figure 1). After habituating infants to one event, we reversed the objects' positions and showed infants test events that either disrupted the spatial properties of the reach while maintaining the same goal relation (new path events) or maintained the spatial properties of the reach while disrupting the goal relation (new-object trials). In our studies, infants at 6, 7, 9, and 12 months have shown a strong novelty response (i.e., longer looking) on new-object trials than on new path trials. This finding has been replicated in several other laboratories (Wellman & Phillips, 2001; Jovanovic *et al.*, 2004; Sodian & Thoermer, 2004; Spaepen & Spelke, 2004).

The initial findings also suggested that infants' propensity to encode actions as object-directed is specific to familiar *human* actions—infants did not respond in the same way to events in which inanimate claws or ambiguous agents grasp objects (Meltzoff, 1995; Woodward, 1998; Guajardo & Woodward, 2004; see also Jovanovic *et al.*, 2004), or to unfamiliar human actions on objects (Woodward, 1999). However, several researchers have suggested that infants interpret novel actions or the motions of unusual agents as goal-directed under certain conditions (Gergely *et al.*, 1995; Johnson, 2000; Kiraly *et al.*, 2003; Luo & Baillargeon, 2004; Shimizu & Johnson, in press). I return to this possibility later in this chapter.

B. SHIFTING ATTENTION TO OBJECTS VS. REPRESENTING AGENT–OBJECT RELATIONS

In the studies just summarized, as in many studies of infant cognition, the goa was to assess infants' representations of event structure via their looking times o test trials. Like other researchers who use this paradigm, we were carefu

to control the factors that could have contributed to infants' visual responses. The same agent and objects were present in each habituation and test trial, with the key variations in the events concerning the relation between the agent and the objects. This, we reasoned, would enable us to determine whether infants' represented the agent–object relation. However, there was a remaining concern: infants' responses on test trials might be a by-product of the way the events entrained their attention on the objects rather than reflecting their representation of the agent–object relation *per se*. This was of particular concern because the events involved the actions of social partners, and these actions have been shown to entrain infants' attention in other contexts. Infants may look "smarter" than they are because adults' actions support their attention to the relevant aspects of the environment. Indeed, debates about infant social cognition hinge on the question of whether infants really understand the relevant intention or instead are simply led to look in the right place at the right time (e.g., Moore & Corkum, 1994; Tomasello, 1995). In the case of the habituation studies we worried that the motion of the hand may have drawn infants' attention to the object, as if it were a spotlight on the object, and then, when the spotlight was directed at a new object during test trials infants looked longer not because the agent–object relation had changed but because they were led to look at a different object.

One way to assess this possibility was to conduct matched control conditions involving events that were not goal-directed. For example, in various control conditions we showed infants rods that touched the objects, hand-shaped cardboard cutouts that partially occluded the objects, mechanical claws that grasped the objects, or apparently purposeless manual contact with the objects. In none of these cases did infants look longer on new-object than new-side trials (Woodward, 1998, 1999; see also Jovanovic *et al.*, 2004). These findings suggest that infants' responses were not driven by the motion of the hand toward the object or its contact with the object—because this motion and contact were present in each of the control events. It still might be the case, however, that grasping hands are more potent spotlights for infants than are inanimate objects and inert hand postures. To evaluate this possibility, we coded infants' attention to each of the toys during test trials. We found that rods, flat cutouts, claws, purposeless hands, and grasping hands were all equally effective in directing infants' attention to the contacted toy. Because these attentional effects were uniform across conditions, they cannot account for infants' differential responses to new-object vs. new-side events across conditions.

These analyses show that infants' overall looking times on test events were driven by their representation of event structure rather than by the effects of the action on their attention to the objects in the display. There are many ways to lead infants to look at an object, including grasping it, touching it with a rod, grasping it with a claw, and dropping one's hand onto it. But directing attention in this way does not determine whether infants represent the event in terms of the relation

between actor and object. Infants only encode events in terms of the actor–object relation in the case of intentional human actions such as grasping, and, as I review next, certain other intentional actions.

C. THERE IS A CONNECTION BETWEEN A PERSON AND THE OBJECT OF HIS OR HER ATTENTION

Instrumental actions, such as grasping, carry concrete indicators of the goals they express. In everyday life, these actions have observable effects, for example, moving a desired object closer to the agent, and these effects may support infants' ability to extract the goal structure of these actions. In contrast, the relation between a person and the object of her attention can only be inferred, and seems, to non-scientist adults and psychologists alike, to be uniquely psychological. Following on this intuition, researchers have long been interested in when and how infants come to understand the invisible connection between a person and the object of his or her attention.

For many years, the main means for investigating this issue was to assess infants' propensity to look in the direction of an adult's gaze shifts. Infants systematically follow adult gaze shifts during the first year of life (e.g., Scaife & Bruner, 1975; Schaffer, 1984; Butterworth & Jarrett, 1991). Researchers have often assumed that if infants turn to follow the adult's line of regard, then they must do so because they understand that the adult is looking at something. The prior discussion illustrates the problem with this assumption. Shifting attention to a location need not indicate that infants have understood the action as object-directed. Indeed, there has long been debate about the significance of infants' gaze-following, with a number of researchers pointing out that gaze-following could result from processes that do not involve a conceptual representation of the "seeing" relation (e.g., Moore & Corkum, 1994).

This debate about the significance of gaze-following indicates that an alternative source of evidence is needed. With this need in mind, we recruited the experimental logic from our studies of grasping to ask whether infants represent the invisible connection between a person and the object of his or her attention (Woodward & Guajardo, 2002; Woodward, 2003). We showed infants events in which a person turned to look at a toy (Woodward, 2003—see Figure 2), in which a person looked at and pointed to a toy (Woodward & Guajardo, 2002), and in which only the person's arm was visible as she pointed to the toy (Woodward & Guajardo, 2002). In each case, infants were habituated to an event in which a person pointed toward (or gazed at) one of two toys. Then, the toys' positions were reversed and infants viewed test events that disrupted either the object to which the person directed pointing (or gaze) (new-object trials) or the person's physical motions (maintaining the same object as the target) (new-side trials). For all the events, the person's actions drew infants' attention to

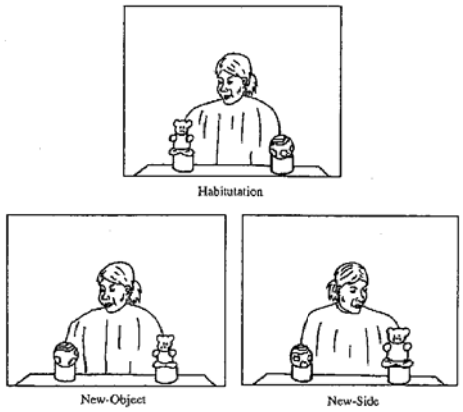

Fig. 2. Sample gaze events for (based on Woodward, 2003).

the indicated toy at all of the ages we studied (7-, 9-, and 12-month-olds). However, only 12-month-old infants responded to a change in the actor–object relation for gaze and pointing: they showed a reliably greater novelty response on new-object trials than on new side trials. Infants younger than 12 months shifted their attention in response to the experimental events, but seemed not to comprehend the significance of the action to which they had just responded.

Observers have long noted that between 9 and 12 months infants seem to "tune in" to their social partners, engaging in more shared attention with their parents and producing as well as responding to communicative gestures (Bakeman & Adamson, 1984; Schaffer, 1984; Tomasello, 1995). Our findings provide evidence that this change in social responsiveness is accompanied by a change in infants' social cognition, specifically, an emerging sensitivity to the relational structure of attentional behaviors. Furthermore, our findings suggest that specific relations exist between infants' social responsiveness and their social cognition. We found that infants' own pointing status was related to their sensitivity to the object-directed structure of pointing. In Woodward and Guajardo (2002) we tested 48 infants between the ages of 8 and 11 months using the habituation paradigm for pointing. For each infant, we also established

(via parental interview and observations in the laboratory) whether the infant produced clear points that were directed toward objects. Eighteen of the infants had begun to produce object-directed points and 30 had not. These two groups of infants did not differ in terms of their age, overall attentiveness or habituation rates. They did differ, however, in terms of their responses on test trials: infants who pointed looked reliably longer on new-object trials than on new-side trials, whereas infants who did not point looked equally on the two kinds of test trials.

The results across our studies of gaze and pointing converge with findings from other laboratories in indicating infants' growing awareness of attentional relations beginning at around 12 months (Phillips, Wellman, & Spelke, 2002; Onishi & Baillargeon, 2004; Sodian & Thoermer, 2004). To illustrate, in one study, Phillips, Wellman, and Spelke (2002) tested whether infants use the inferred relation between a person and the object of her attention to predict her subsequent actions. During habituation, infants saw a woman first look at and then pick up one of two toys. Then, infants viewed test events in which the woman looked at and then picked up the other toy (consistent actions), or in which she looked at the first toy but picked up the other one (inconsistent actions). At 12 months (but not 8 months), infants looked longer at the latter than the former, indicating that they detected the inconsistent relation between the woman's gaze and her subsequent actions. At 14 months, infants expected the woman to act on the prior object of her attention even when they were not habituated to a full "look and then grab" sequence.

Experiments that capitalize on infants' social responding provide further evidence for an emerging understanding of attentional relations at the end of the first year. As noted previously, infants follow gaze from early in the first year of life, and our findings suggest that this early gaze-following does not rest on an understanding of attentional relations. However, at 12–14 months, infants begin to modulate their gaze-following in ways that suggest they understand the connection between a person and the object at which her gaze is directed as well as the physical constraints governing this connection: specifically, they refrain from following an adult's gaze when the adult's eyes are closed or when there is a barrier between the adult's eyes and the object (Brooks & Meltzoff, 2002; Dunphy-Lelii & Wellman, in press; see also Butler, Caron, & Brooks, 2000 for similar evidence with older infants). Moreover, 12- to 18-month-old infants have been shown to use an adult's gaze direction to interpret his or her referential expressions (e.g., Baldwin, 1995; Moses *et al.*, 2001; Tomasello & Haberl, 2003; Woodward, 2004a). To illustrate, Moses and colleagues (2001) found that 12-month-old infants relate an adult's expression of disgust to the object at which the adult was looking, even when infants were unable to view the object themselves.

D. THE SAME MOTION MIGHT OR MIGHT NOT BE GOAL-DIRECTED IN DIFFERENT CONTEXTS

The evidence reviewed so far shows that during the first year infants represent several common actions, grasping, looking, and pointing, as being object-directed. These actions are potent signs of goals and intentions for adults, so much so that they have become metaphors for more abstract intentional relations (e.g., "The prize was just beyond my grasp" or "I see what you mean"). However, mature observers are not limited to understanding certain canonical actions as expressing intentions. Rather, we can flexibly interpret actions online, using the context to infer the goals or intentions behind ambiguous or novel actions. This ability is based in the knowledge that goals or intentions do not reside in the particular actions that they drive. To the extent that infants can also flexibly represent actions as goal-directed or not, then, this indicates that they may also understand goals as being distinct from particular actions.

Studies from several distinct paradigms support the conclusion that by 9–12 months of age, infants interpret actions based on the context in which they occur, including the physical context (such as whether the action is a rational means to attain the goal given the physical obstacles present) as well as the other actions the agent produces (such as facial and vocal expressions of frustration or surprise). In a striking demonstration of the first of these, Gergely *et al.* (1995) found that 12-month-old infants responded to a computer-animate shape traversing a looping path as being goal-directed when it circumvented a wall to approach another shape, but did not respond in this way to the same path of motion when there was no wall present. The looping path was apparently a rational route to the other shape when the wall was present, but not when it was absent. Gergely and colleagues concluded that infants evaluated the rationality of the shape's motion, and responded to the rational path as evidence of goal-directedness (see also Csibra *et al.*, 2003). Csibra and colleagues (1999) obtained a similar result at 9 months, and other studies have confirmed that infants respond in the same way when the moving entity is a person rather than a computer animation (Sodian, Schoeppner, & Metz, 2004).

Behne and colleagues (in press) reported converging evidence from a paradigm that manipulated infants' social responses. They engaged infants in a game in which an experimenter handed the infant a series of small toys. After several exchanges, the experimenter failed to hand the infant a toy, in some cases acting as if she was unwilling to complete the transfer, and in other cases acting as if she was unable to do so. These two cases were designed to involve similar movements. For example, the adult would hold out a toy and then teasingly pull it out of reach in one case, and hold it out and then "accidentally" drop it in the other. Behne and colleagues found that infants as young as 9 months of age responded with more frustration when the adult was unwilling to hand them the toy than

when she was apparently unable to do so. Across items, infants seemed to recruit several different kinds of information to make sense of the two kinds of actions, including the causal constraints present (e.g., the toy was out of reach) as well as the adults' facial and vocal behaviors indicating an intent to tease. Though methodologically quite different from the work by Gergely and Csibra, this finding supports a similar conclusion: by 9 months of age, infants represent very similar motions as being object-directed or not based on contextual information.

Infants younger than 9 months did not respond systematically in either the habituation paradigm developed by Gergely, Csibra and colleagues or in the paradigm developed by Behne and colleagues. One possibility is that although younger infants are sensitive to the goal-directedness of some familiar actions, they are not able to flexibly interpret actions based on contextual information. Alternatively, younger infants may be unable to draw on the particular kinds of contextual information provided in these studies, but able to use other aspects of the situation to interpret actions as goal-directed. In line with this possibility, several researchers have proposed situational and behavioral cues that are hypothesized to support young infants' interpretation of actions as goal-directed. Kiraly and colleagues (2003), for example, propose that when an action has an observable causal effect on the object (i.e., it causes an object to move), or when repeated actions apparently pursue the same goal via different routes, then infants interpret the action as goal-directed. The evidence for these proposals is considered subsequently because it bears on debates about the innate contributors to infants' action knowledge.

E. ACTIONS CAN BE ASSEMBLED IN SERVICE OF OVERARCHING GOALS

Adults are not limited to understanding the goal structure of single actions such as grasps or glances, but can understand sequences of actions as being organized by overarching goals (Schank & Abelson, 1977; Searle, 1983; Zacks & Tversky, 2001). For example, seeing someone walk to the cupboard, grasp the knob, pull open the door, and then grasp a box of cookies inside, we understand not only the goal of each component action (e.g., opening the cupboard), but also the overarching goal that drives the sequence (getting something to eat). Zacks and Tversky (2001) describe this aspect of action structure in terms of *partonomic hierarchies*: actions organized by subgoals form the parts of a sequence organized by a higher order goal. Analyzing action sequences in this way is integral to mature event representation (e.g., Searle, 1983), and this hierarchical structure is evident in adults' and children's memories for and descriptions of complex events (Trabasso *et al.*, 1992; Baldwin & Baird, 2001; Bekkering, Wohlschlaeger, & Gattis, 2000; Zacks, Tversky, & Iyer, 2001). Moreover, this aspect of action knowledge structures imitative learning by the second year of life (Wenner & Bauer, 1999; Gergely, Bekkering, & Kiraly, 2001).

Because of its centrality to mature conceptions of intention, developmental psychologists have considered hierarchical action representation to be a hallmark of both having intentions (Piaget, 1953) and representing the intentions of others (Gergely *et al.*, 1995; Meltzoff, 1995; Tomasello, 1999). The findings reviewed so far indicate that some of the prerequisites for this ability emerge during the first year. Infants can detect the goal structure of single actions early in the first year, and, by 9–12 months, infants can interpret a single action as goal-directed or not based on contextual information. Furthermore, 9- to 12-month-old infants sometimes assume that sequential actions, such as looking and grasping, will be directed at the same object (Phillips, Wellman, & Spelke, 2002; Sodian & Thoermer, 2004).

These findings raise the question of whether infants could also interpret the same action as being directed at goals at differing hierarchical levels. To investigate this question, we have introduced infants to action sequences in which a person acts on one object in order to gain access to another object. These sequences have a simple hierarchical structure in which the action on the first object is interpretable either as directed at that object (the proximal goal) or at the object obtained a the end of the sequence (the ultimate goal). To illustrate, in one study (Woodward & Sommerville, 2000), 12-month-old infants saw an actor reach toward and grasp the lid of one of two transparent boxes, each of which contained a toy (see Figure 3). The actor proceeded to open the box and then grasp the toy inside it. The question of interest was whether infants interpreted the first action, the grasp of the box lid, as directed at the box itself or

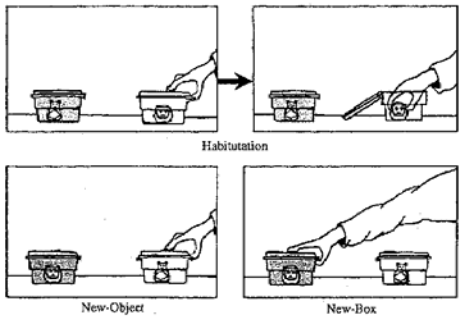

Fig. 3. Sample means-end events (based on Woodward & Sommerville, 2000).

instead at the toy inside the box. Infants were habituated to one box-opening sequence (see Figure 3 for an example). After habituation, the positions of the toys were reversed, and infants saw new-object test trials (in which the actor grasped the same box as during habituation, which now contained a different toy) and new-box trials (in which the actor grasped the other box, which now contained the toy that had been in the contacted box during habituation). In each case, the adult grasped the box lid but did not complete the sequence. Thus, these trials provided a test of how infants interpreted the first action in the sequence (grasping the box lid). If they interpreted it as directed at the box itself, they should look longer on new-box trials; if they interpreted the initial grasp as directed at the toy within the box, they should look longer on new-toy trials. Twelve-month-old infants showed the latter pattern, looking longer when the actor grasped the same box that now contained a different toy. Thus, they "read ahead" in the sequence, and responded to a change in the ultimate goal rather than a change in the proximal goal, even though the actor did not go on to complete the sequence.

On what basis did infants read ahead? One possibility is that infants relate actions to ultimate goals based solely on their order of occurrence—that is they may assume that actions are directed at the goals, which follow them. Infants are adept at extracting sequential patterns in temporally ordered stimuli (Saffran, Aslin, & Newport, 1996) and this has been hypothesized to contribute to their action analysis (Baldwin & Baird, 2001). However, adults do not analyze action based only on sequential ordering. In relating actions to higher order plans, we draw on contextual evidence including information about the causal constraints on action. When an action physically enables the attainment of a goal, then we may interpret the action as directed at that goal. As described previously, Gergely, Csibra and others have shown that infants use such evidence to infer whether or not a particular path of motion is goal-directed (Gergely *et al.*, 1995; Csibra *et al.*, 1999), and this raises the possibility that infants may also be able to use causal relations to relate subgoals to higher order goals.

To address this question, we conducted a follow-up to the box-opening study (Woodward & Sommerville, 2000, Study 2), testing whether infants related the actions based only on their sequential ordering, or, instead drew on the causal relation between them (opening the box enabled the actor to grasp the toy). The events were the same as in the first study except that now the toy sat outside the box rather than in it. Thus, although the temporal relation between the actions was maintained, the causal relation between them was disrupted. Under these conditions, infants looked marginally longer on new-box trials, indicating that when there was no causal relation between the actions, infants did not interpret the grasp of the box lid as directed at the toy. In other words, infants, like adults, draw on causal relations as evidence about the higher order goals at which actions may be directed.

In a later series of studies, we replicated these results at 12 months using a different means-end problem, pulling a cloth to obtain a toy (Sommerville & Woodward, 2005). We then went on to test younger infants, 10-month-olds, and found that as a group they responded randomly to the test events. However, additional measures and analyses revealed underlying individual variation in infants' responses at this age. Each infant also completed an action task, in which they were presented with a toy out of reach on a cloth, and their task was to bring the toy within reach. There was a positive correlation between the extent to which infants produced planful responses on the action task (maintaining eye-contact with the toy while pulling it into reach and then grasping the toy as soon as it came near) and their preference for the new-object event over the new cloth event in the habituation task. Moreover, an analysis of the habituation performance of the upper and lower 25% of infants in the action task revealed two distinct patterns of response: the most planful infants looked reliably longer on new-object trials, indicating that they interpreted the actor's grasp of the cloth as directed to the toy, and the least planful infants looked longer on new cloth trials, indicating that they interpreted the grasp of the cloth as directed toward the cloth. Thus, at 10 months, some infants endorsed one interpretation of the action—grasping the box was directed at the box itself—whereas others endorsed the more abstract interpretation—grasping the box was directed at the toy inside.

In summary, by 10–12 months, infants attend not only to the local relations between actions and objects, but also to relations between actions and ultimate outcomes. An action, grasping, that can readily be interpreted as directed at the object grasped can be re-interpreted as directed a goal further along in the sequence, so long as a causal chain connects the actions. By the end of the first year, then, infants have begun to extract the partonomic hierarchical structure of action.

F. CONCLUSIONS: WHAT INFANTS KNOW

During the first year of life infants begin to analyze action in terms of its intentional structure. This analysis goes beyond the surface level of motions and contact, reflecting meaningful components of human behavior. This analysis is first evident in 5- to 6-month-old infants' propensity to relate agents to goals for actions that appear purposeful, in particular, grasping. Between 9 and 12 months, infants begin to relate agents to the objects of their attention, and also begin to relate actions in a sequence to one another in situations in which these relations are likely to be meaningful. Converging evidence for these conclusions has emerged from studies across several laboratories and from different paradigms, including not only visual habituation measures of infants' event representation, but also experiments that manipulate infants' overt social responses.

These findings raise the question of how infants understand the intentions behind the structure. Infants represent certain actions in terms of the relation

between the agent and the object at which her actions are directed, but what do they understand about the nature of this relation? Adults both represent the behavioral regularities associated with action and infer the mental states that underlie these regularities. One possibility is that infants do the former but not the latter. For example, infants may understand the relation between agent and object in terms of likely subsequent actions (e.g., a person is likely to act on the object at which he or she has just looked), and this could then lead them to preferentially encode agent–object relations (see Woodward, 1998, 2003, in press).

Even if infants begin with a purely behavioral analysis of action structure, there are reasons to believe that this could be a step in the construction of mature conceptions of intention. A behavior-based analysis of agent–object relations that leads infants to attend to relations between agents and goals, and agents and the objects of their attention highlights the aspects of events that are likely to be useful for constructing richer knowledge about intentions. In other words, a behavioral analyses of action could provide the foundation for insights about the psychological correlates of action (*cf.* Whiten, 1994). As another example of this possibility, Gergely and Csibra (1998, 2003) hypothesized that infants' analysis of actions as rationally organized toward goals (teleological representations) exists prior to and provides a foundation for the construction of knowledge about the mental causes action: infants' initial teleological representations specify the relations between agents and observable goals given observable states of affairs. These representations are hypothesized to provide the foundation for the conceptual insight that goals are mental entities (desires) that are pursued with respect to mentally represented states of affairs (beliefs).

Thus, infants might hold relatively abstract expectations about certain kinds of motion, and yet not conceptualize these expectations in terms of mental states. Alternatively, infants may understand something about the inner states that drive action. In considering this possibility, I first raise two caveats. One is that there are aspects of mental life that even preschool-aged children do not yet fully understand, including the representational nature of beliefs (Flavell & Miller, 1998; Wellman, Cross, & Watson, 2001), and these are fundamental to mature folk conceptions of mental life. Therefore it seems extremely unlikely that infants possess the explicit and elaborate system of knowledge that is evident in later in childhood.

The other caveat is that the kinds of data that can be obtained from infants may never completely resolve this question. Older children's talk about the mind has been an invaluable source of evidence for their mentalistic understanding (Astington, 1993; Bartsch & Wellman, 1995), and of course such evidence is not available from infants. Because infants do not understand or use the words that name mental states, our best evidence will necessarily be their behavioral responses to observed actions, and these responses are often, if not always, open

to the interpretation that infants represent (important) behavioral regularities, but not mental states (see Johnson, 2000).

Even given these concerns, there is evidence consistent with the conclusion that 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 residing within the individual agent, and as having the same form in oneself and in others. In their tracking of action information, infants evidence understanding of each of these aspects of mental experience by the end of the first year of life.

First, as discussed earlier, infants represent the non-physical relation between a person and the object of his or her attention, and further, represent goals as being independent of particular actions. Each of these abilities indicates that infants represent something more abstract than the immediate physical connections between agents and objects. Indeed, these two abilities have been widely viewed as evidence that infants understand mental states of attention (Leslie, 1993; Barresi & Moore, 1996; Tomasello, 1999; Johnson, 2000) and plans held in mind (Behne *et al.*, in press; Meltzoff, 1995; Carpenter, Nagell, & Tomasello, 1998).

Second, infants represent goals as attributes of individual agents. We have found that 9- and 13-month-old infants represent the identity of the agent as integral to the goal of an action (Sootsman & Woodward, 2004). We used a habituation paradigm, similar to our prior studies, in which infants viewed a person directing actions toward a particular goal object, and then saw test events in which the physical context was changed and the actor acted either in accordance with the prior goal or a new goal. Changing the identity of the actor between habituation and test disrupted infants' propensity to respond to the change in goal. In other words, infants did not to attribute the goal of the first actor to the second actor. Kuhlmeier, Wynn, and Bloom (2003) addressed a similar question from a different vantage point, asking whether 12-month-old infants would attribute enduring dispositions to individual agents. Infants viewed geometric shapes interacting in a animated film. One of these shapes repeatedly moved in a way that suggested it was harassing another. Infants expected the victim to subsequently selectively avoid the harasser when given a choice. Thus, infants apparently attributed a particular (negative) disposition to the victim that provided a basis for inferring the victim's actions in a novel context.

Third, as I review in more detail subsequently, there is a tight relation between infants' own experiences as agents and their understanding of others' goal-directed actions. Infants' understanding of familiar actions as goal-directed emerges at the same time as their own mastery of these actions becomes robust (Woodward, Sommerville, & Guajardo, 2001; see also Molina *et al.*, 2004), there are correlations between action production and action comprehension during these periods of emergence (Woodward & Guajardo, 2002; Brune, 2004; Sommerville & Woodward, 2005), and interventions that alter infants' own

agentive experience also alter their representation of others' actions (Sommerville, Woodward, & Needham, in press). In addition, there are well-documented self-other connections in the other direction—infants shape their own goal-directed actions to match those of others from very early in life (Meltzoff & Moore, 1977; Meltzoff, 2002). These findings all suggest that infants represent their own and others' goals in similar formats, and further, that to the extent that infants are aware of their own inner intentional states, they may be able to attribute similar states to others.

Although none of these findings conclusively proves that infants understand mental states, they converge in suggesting that central aspects of mental state knowledge have begun to emerge in infancy. Ultimately, the question of whether infants "really" understand mental states may elude a definitive answer, in part because of limits on infants' channels of knowledge expression, and in part because the question will have different answers depending on which aspects of mature mental state knowledge are taken to be criterial. Nevertheless, and I think more importantly, we have learned a great deal about infants' emerging action knowledge. During the first year, infants' action knowledge includes some of central elements of mature systems of knowledge. Because infants represent the relevant aspects of action structure for understanding the intentions of others, their action knowledge is likely to be generative in at least two ways: First, it would provide the foundation for the subsequent development of more abstract and differentiated folk psychological knowledge. Second, it could account for the "smart" social learning described at the start of this chapter. Representing goal-directed actions, attentional relations, and higher order plans would lead infants to focus on the right aspects of situations to learn words, infer the referents of emotional expressions, and extract the meaningful components of others' actions (see Woodward, 2004a).

III. Origins of Infants' Action Knowledge

The findings just summarized provide an initial framework for the emergence of infants' action knowledge, and thereby raise the question of how this knowledge originates. Among the enduring debates in the fields of cognitive science and developmental psychology is the question of whether foundational aspects of conceptual structure are the expression of innate abstract knowledge systems, or instead the product of bottom-up learning and conceptual construction. This debate has been particularly active in the domain of social cognition, especially because the evidence for intentional action knowledge in infancy raises the possibility that there are innate contributors to this system of knowledge. As in the field in general, the initial nature-nurture debate on this issue has become more nuanced, focusing not on whether there are innate

contributors to this system of knowledge, but instead, on what these might be and the relative contributions of innate and experiential factors.

Within this discussion, three general proposals about the ontogeny of intentional action knowledge have been elaborated, and I review them below. Although in their strongest form these proposals seem incompatible, ultimately it is possible that elements of each may be shown to contribute to infants' emerging action knowledge. At this point, the field has just begun to gather the data that test the limits of each proposal.

A. INNATE ABSTRACT CONCEPTS

A well-known proposal, articulated in an influential theoretical paper by Premack (1990), is that infants begin life with abstract systems for interpreting observed events as intentional. Following Premack's proposal, a number of similar proposals have emerged, each differing in important ways, but all beginning from the assumption that the innate intentionality-detection system exists independent of experience with real-world agents, and is triggered by particular patterns of motion. Kiraly and colleagues (2003) summarized these proposals as follows:

> Several theories propose innately based, abstract, and domain-specific representational systems specialized for identifying intentional agents...While these models differ in several important respects, they all assume an initially wide scope of entities...that infants can recognize as goal-directed from very early on (including unfamiliar actions of humans or unfamiliar agents with no human features). This generality in scope is due to the fact that these theories all postulate or imply sensitivity to abstract behavioural cues...that indicate agency...irrespective of previous experience with the types of agents or actions that exhibit these cues (2003, p. 753).

Premack proposed that the triggering cue is self-propelled motion, suggesting that any self moving object would be identified as an agent, and its behaviors then be interpreted as manifesting intentions, preferences, the capacity to learn, and other psychological phenomena (see also Luo & Baillargeon, 2004). In this case, a single behavioral cue triggers a system of innate beliefs. In a similar account, Johnson (2000; Shimizu and Johnson, 2004) have hypothesized that when an entity engages in contingent social interaction, infants infer that it is an agent that can attend to distant entities and act in goal-directed ways.

In other accounts, the behavioral triggers are also the embodiment of the hypothesized innate concept (*cf.* Leslie, 1993; Gergely & Csibra, 2003; Kiraly *et al.*, 2003). In other words, the innate concept explains particular behavioral patterns, and the system fires to any event that manifests these patterns. Gergely, Csibra, and colleagues (Gergely *et al.*, 1995; Csibra *et al.*, 1999, 2003; Gergely & Csibra, 2003) proposed seeing an entity move with apparently rational motion in pursuit of a goal triggers innate conceptions of

rational action, and leads infants to expect that the entity will act rationally in new situations. Kiraly and colleagues (2003) have proposed that two additional cues have this effect (1) motion that causes a salient outcome, and (2) repeated, varied (equipotential) motions to the same goal. Each of these, organization of actions in terms of outcomes and equipotentiality, are hypothesized to be part of the content of innate conceptions of intentional action.

All of these accounts predict that infants possess relatively abstract conceptions of intentional action that they apply to any object that moves in the critical way, regardless of whether the object bears any resemblance to a real-world agent. A number of findings provide support for this prediction in older infants. One source of evidence derives from studies like those of Gergely, Csibra, and colleagues (Gergely *et al.*, 1995; Csibra *et al.*, 1999, 2003) and Kuhlmeier, Wynn, and Bloom (2003), that were summarized earlier. In these studies, 12- and sometimes 9-month-old infants respond to the motions of abstract figures on a computer screen in ways that suggest they have interpreted these motions as goal-directed.

A second source of evidence are findings by Johnson and colleagues suggesting that viewing an entity engage in socially contingent behaviors influences infants' subsequent propensity to regard the entity as an agent (Johnson, Slaughter, & Carey, 1998; Johnson, Booth, & O'Hearn, 2001; Shimizu & Johnson, 2004). To illustrate, Shimizu and Johnson. (2004) introduced 12-month-old infants to a fuzzy green block. One group of infants first viewed the block responding contingently to the social bids of an experimenter (by beeping and moving). A comparison group viewed the block and heard it beep, but did not see an interaction between the object and the experimenter. Then both groups of infants saw the block approach (with apparently self-propelled motion) and make contact with one of two target objects. Infants were habituated to this event. Then, as in the procedure developed in Woodward (1998), the target objects' positions were reversed and infants were shown new-object test trials (the block moved to the same location to contact the other object) and new-location test trials (the block moved to the other location to contact the same object as during habituation). Infants who had not viewed the contingent social interaction did not differentiate between the test events, suggesting that they did not interpret the block's motions as goal-directed. Infants who had viewed the interaction, in contrast, looked reliably longer on new-object than new-location trials, suggesting that they did interpret the block's motions as goal-directed. Thus, these findings suggest that the social interaction led infants to construe the block as an agent.

These findings indicate that by the time infants are 9--12 months of age, they possess relatively abstract conceptions of goal-directed action that can be extended to unusual agents in some circumstances (but not all, see Meltzoff, 1995; Guajardo & Woodward, 2004). However, the further claim that this

abstract knowledge is innate is largely untested. Because nearly all of the relevant findings pertain to infants who are 12 months of age or older, they may be the products of a developing system rather than an innate endowment (see Woodward, Sommerville, & Guajardo, 2001; Guajardo & Woodward, 2004). Infants' action knowledge may derive from experience with real-world agents and their actions, and become more abstract and flexible with development. As infants acquire knowledge about specific actions and the relations between them, they may extract regularities across actions, and then use these regularities to inform their interpretation of novel or ambiguous events.

If infants' initial conceptions of goal-directed action were abstract, then infants would broadly attribute goals from the start, either from birth, or from the first point at which they attribute goals to any entity. Several sources of evidence suggest that this is not the case. To start, as reviewed earlier, our prior findings showed that although infants interpret the familiar actions of people as goal-directed beginning as early as 5 or 6 months of age, they do not interpret the motions of inanimate objects or unfamiliar human actions in this way (Woodward, 1998, 1999). Furthermore, we found that infants' propensity to view a grasping event as goal-directed was modulated by the extent to which infants could identify the hand as part of a person (Guajardo & Woodward, 2004). It has been suggested (see Kiraly *et al.*, 2003; Shimizu & Johnson, 2004) that these failures are due to the fact that the unfamiliar actions and object motions in those studies, though carefully matched to the familiar human actions, did not possess the behavioral cues hypothesized to trigger infants' goal attribution. However, when these cues have been provided, younger infants still fail to interpret unfamiliar events as goal-directed. Csibra and colleagues (1999) tested 6-month-old infants with computer animations of rational motion around barriers, and these infants, unlike older infants, failed to respond systematically. Kiraly and colleagues (2003) tested 6-, 8-, and 10-month-olds in a paradigm designed to assess whether providing a salient action effects would lead infants to interpret an unusual action as goal-directed. Their findings suggested that 8- and 10-month-olds, but not 6-month-olds, responded to the events as goal-directed (but see Heineman-Pieper & Woodward (2003) for an alternative interpretation of the older infants' responses). Jovanovic and colleagues (2004) conducted similar studies with 6-month-old infants and reported mixed findings. Infants apparently interpreted a human hand gesture as goal-directed, but did not respond to grasping by a mechanical claw in this way.

Thus, the available findings are most consistent with the conclusion that infants begin with local understandings of goal-directed action that become broader over the course of the first year of life. Further research is needed to thoroughly test this conclusion, however. There are several hypotheses concerning the potential behavioral triggers to innate knowledge, and current studies may not have presented young infants with the right one. As a possible case in point,

Luo and Baillargeon (2004) reported that 6-month-old infants apparently interpreted a self-propelled box as a goal-directed agent. However, this report is inconsistent with the findings of Shimizu and Johnson (2004) who found that infants did not treat a self-propelled block as goal-directed.

B. SOCIALLY BASED COGNITIVE LEARNING

The counterpoint to strongly nativist proposals are accounts that consider conceptual structure to be the product of bottom–up learning and conceptual abstraction. Researchers have made important strides in investigating the role of these processes in older children's cognitive development (e.g., Gentner & Medina, 1998; McClelland & Siegler, 2001; Samuelson & Smith, 2000) and have begun to consider the role of these processes during infancy (Mandler, 1998; Baillargeon, 2002; Cohen, Chaput & Cashon, 2002; Rakison & Oakes, 2003). It has been hypothesized that associative learning (Rakison & Poulin-Dubois, 2001), statistical learning, and structure mapping (Baldwin & Baird, 2001) each contribute to infants' emerging social cognition, but these proposals have not been directly tested.

The proposal that intentional action knowledge is the product of cognitive learning has also been developed by researchers who focus on the influence of social experiences on infants' social cognition (Tomasello, 1995; Barresi & Moore, 1996; Carpenter, Nagell & Tomasello, 1998; Carpendale & Lewis, 2004). These accounts generally focus on 9–12 months of age, a period during which infants begin to engage in more robust and well-structured interactions with adults, including shared attention, communicative gestures, game playing, and imitation. The onset of these new ways of interacting is striking, and has been taken by many to signal a "social-cognitive revolution", and, in particular, newly emerged understandings of intentional action (Tomasello, 1995).

These emerging interactive patterns are taken not only as the sign of new social-cognitive abilities, but also as the means by which these abilities arise. Specifically, it has been hypothesized that engagement in triadic interactions sets the conditions for infants' discovery of others' intentions (Barresi & Moore, 1996; Carpenter, Nagell & Tomasello, 1998; Carpendale & Lewis, 2004). In these interactions, adult and child attend to (and sometimes act on) the same aspect of the environment, thus providing the opportunity for infants to align their own actions and intentional states with the observed actions of others. This alignment of self and other has been suggested to provide infants with the structural components necessary to infer intentional relations between others and the objects of their attention. Some propose that infants begin with a merged representation of their own intentional relations and those of others, from which they then construct differentiated concepts of themselves and others as

independent agents (Barresi & Moore, 1996; Carpendale & Lewis, 2004). Other theorists suggest something more like a process of analogical extension from self to other; that is, that infants infer that others have internal experiences analogous to their own (Carpenter, Nagell, & Tomasello, 1998; Meltzoff, 2002).

These accounts are both plausible and potentially deeply informative about cognitive development in infancy. They take seriously the roles of rich environmental structure and cognitive learning processes in infants' developing social cognition. Moreover, they are consistent with what is known about the subsequent development of this system of knowledge: there are widely documented effects of social environments on the development of folk psychological knowledge in older children (see Dunn, 1999; Repacholi & Slaughter, 2003; Carpendale & Lewis, 2004 for reviews). However, little headway has been made in empirical tests of these accounts with respect to infant social cognition.

One reason for this is that these accounts often rely on social responsiveness as an index of intentional understanding, and this compromises their ability to draw strong conclusions about the nature of infants' social cognition. There has long been debate about whether and when children's social responses can serve as evidence about their comprehension of others' intentions. Indeed, even among those who take social responsiveness as evidence of underlying action representations, there is serious disagreement about which behaviors "count". For example, Tomasello (1995) has suggested that the gaze-following and joint attention behaviors of 9- to 12-month-olds reflect an understanding of others' intentions. But Barresi and Moore (1996) (see also Moore & Corkum, 1994) point out that these behaviors might be shaped by reinforcement or supported by low-level processes that do not require an understanding of attentional relations. More generally, overt social behaviors are likely to be influenced by processes at several levels, and therefore there is no straightforward relation between the behavior and a particular mental representation. In addition, reliance on organized triadic behaviors as evidence for organized social cognition is likely to underestimate what young infants know. Infants younger than 9–12 months of age do not yet participate in well-organized triadic interactions, however, as summarized previously, they do understand critical aspects of intentional action (see Wilson & Woodward, 2003). Clearer evidence about infants' social cognition is needed, and, as described earlier, habituation paradigms have begun to yield such evidence.

A second barrier to testing the social-construction theories is that essentially the same behaviors are considered to be both cause and effect. Aspects of social responsiveness are seen as both contributors to infants' emerging action knowledge and evidence for the existence of this knowledge. For example, it has been suggested that engaging in triadic interactions, in which infant and adult share attention on an object, both provides a means by which infants

discover the adult's attentional relations, and constitute evidence that infants understand these relations. It is entirely plausible that social experience contributes to infants' underlying knowledge about action, but to test this possibility (and determine the specific ways in which it may be true), an independent measure of social knowledge is required.

Brune and I addressed this empirical gap by combining measures of social responsiveness with habituation measures of infants' action understanding (Brune, 2004). Our goal was to determine whether infants' action understanding is correlated with their social responsiveness during a period when both are undergoing important changes, that is between 9 and 12 months. If they are correlated, then this provides initial evidence that experience may contribute to the development of infants' social cognition. This result would then pave the way for investigations that pinpoint the direction of causation.

We tested 10-month-old infants, who, based on our prior findings, are just beginning to understand the attentional relations expressed by gazing and pointing. Each infant was tested in two habituation procedures on different days, one assessing their understanding of gaze, the other their understanding of pointing (as described in Section II.C). The infants were variable in their responses on test trials, showing no systematic group level pattern. Our question was whether this variability correlated with infants' social responsiveness. To this end, we also tested each infant in laboratory procedures assessing several aspects of their social responsiveness, including gaze-following, engagement in shared attention with parents, and ability to point at objects.

We found relations between infants' habituation responses and their social behaviors, but these relations were different than might be expected. The theories outlined previously predict relatively global relations between infants' actions and social cognition—all of the behaviors marking the social-cognitive revolution are supposed to lead to (and express) a unified concept of intentional action. Our findings tell a different story. The relations between infants' social behaviors and social cognition appear to relatively action-specific. Infants' understanding of pointing was significantly related to their own ability to point, replicating our earlier work (Woodward & Guajardo, 2002), but was not correlated with the other measures of social responsiveness. In contrast, infants' understanding of gaze correlated with the extent to which they engaged in shared attention with caretakers, but not with point production or the other social behaviors we assessed. Neither aspect of action understanding related to infants' propensity to follow gaze, consistent with our prior findings that orienting to actions does not always travel with understanding the action as object-directed (Woodward & Guajardo, 2002; Woodward, 1998, 2003).

Documenting concurrent correlations between social cognition and social responsiveness breaks new ground, and indicates that visual habituation data may

(at least in this case) be reliable enough to use in further investigations. However, this evidence alone cannot tell us whether social experiences contribute to the development of social cognition. Longitudinal work is needed to determine the direction(s) of causation that accounts for the relations we observed. It seems likely that the influence is bi-directional by early childhood. However, at the earliest points in development the influence may run in only one direction. Infants' first insights into the intentional states of others may derive from social experiences that are organized by factors other than the infants' social cognition, including the structured behavior of parents and lower level processes that subserve infants' responses to them.

Our findings also begin to shed light on the nature of the relations between social interaction and social cognition during early development, suggesting that they exist at the level of particular aspects of social cognition and particular kinds of social behaviors. Producing points relates to (and may therefore contribute to) infants' understanding the significance of other people's points (see Woodward, in press; Woodward & Guajardo, 2002). Engaging in shared attention relates to (and may therefore contribute to) understanding the significance of others' gaze. These findings raise the question of when and how infants' action knowledge becomes more general.

C. EMBODIED ACTION REPRESENTATIONS

It has long been hypothesized that the experience of being an intentional agent contributes fundamentally to the development of concepts of intention. This general proposal plays a role in several theoretical accounts, including those reviewed in the previous section. Independent of, but relevant to, these accounts, there has been renewed interest in the possibility that experience as an agent informs understanding of other agents because recent findings indicate the existence of shared neuro-cognitive representations for action production and action perception (Gallese & Goldman, 1998; Blakemore & Decety, 2001; Meltzoff & Prinz, 2002).

Evidence for these shared representations has emerged from several diverse research programs. Single cell recordings in monkeys have revealed a class of motor neurons that fire both when the animal is about to produce a particular goal-directed action and when the animal observes a person produce that action (Rizzolatti, Fogassi, & Gallese, 2000). These "mirror neurons" respond to specific natural goal-directed actions (e.g., grasping or tearing), and also have been found for novel goal-directed actions, in particular tool use, following training (Rizzolatti & Arbib, 1998; Rizzolatti, Fogassi, & Gallese, 2000). Using neuroimaging techniques, other researchers have found areas in the adult human brain that have a similar mirroring function (Iaccobini *et al.*, 1999; Grezes & Decety, 2001). Furthermore, behavioral studies with adults have revealed

overlapping cognitive representations that subserve the perception and production of simple actions, as evidenced by interference across these two modalities (Hommel *et al.*, 2001).

These shared representations may exist primarily to monitor self-produced actions, a critical function for the prospective control of action, and because of this function they also fire in response to actions produced by others (Rizzolatti, Fogassi, & Gallese, 2000). It has been hypothesized that these systems contribute to the subjective sense of one's own intentionality (Frith, 2002) as well as to the perception of others' intentional actions (Gallese, 2001; Frith, 2002), and, by extension, to mind reading (Gallese & Goldman, 1998. Blakemore & Decety, 2001; Meltzoff & Prinz, 2002). This speculation is in line with more general proposals about embodied cognition, in particular, the suggestion that sensorimotor representations provide structure for "off-line" cognition, in this case, the interpretation of observed actions (see Wilson, 2001).

Although there is no direct evidence from infants that is comparable to the single cell work with monkeys or the fMRI work with adults, there are reasons to suspect that mirroring systems exist in infants. First, infants imitate others' actions from birth, thus suggesting an automatic resonance between their own actions and those of others (Meltzoff & Moore, 1977; Meltzoff, 2002; Meltzoff & Prinz, 2002). Second, if mirroring systems are important for monitoring and prospective control of actions, then there is every reason to expect their existence in organisms who engage in complex prospective action, and infants do this (see Hofsten, 2004). Beginning early in the first year, infants become able to control actions, such as reaching and grasping, that are organized with respect to external goals (Bertenthal & Clifton, 1998; Clearfield & Theler., 2001; Hofsten, 2004), and it is possible that the systems for monitoring these actions involve mirror representations.

If mirroring systems exist in infancy, then infants' emerging ability organize their own actions in service of goals would create representations that could in turn structure their perception of others' actions. On the basis of neonatal imitation, Meltzoff has proposed that this is the case (Meltzoff, 2002). However, a thorough test of this hypothesis requires measures of infants' action representations as well as their actions. Visual habituation measures like the ones we have developed provide a tool for such investigations.

Indeed, several findings from our laboratory suggested to us that infants' initial action representations derive from their own actions. To start, infants' initial sensitivity to object-directed action appears to be limited to human actions, and actions in infants' own repertoires (e.g., grasping) (Woodward, 1998, 1999; Guajardo & Woodward, 2004; but see Jovanovic *et al.*, 2004). In addition, infants become sensitive to the goal-structure of actions during the age periods that they are mastering production of these same actions (Woodward, Sommerville, & Guajardo, 2001; see also Molina *et al.*, 2004). Finally, at these transitional

periods, infants' mastery of a particular action is related to their sensitivity to the goal-structure of that same action in others, as was reviewed previously for infants' understanding of object-directed points and means-end sequences (Woodward & Guajardo, 2002; Brune, 2004; Sommerville & Woodward, 2005).

As a strong test of whether motor experience affects infants' responses to observed actions, Sommerville, Needham and I conducted an intervention study (Sommerville, Woodward, & Needham, in press). Our goal was to scaffold infants' ability to produce a new goal-directed action, and then test whether this experience affected their response to an observed action. We tested 3-month-old infants. At this age, infants are very limited in their ability to reach for objects, and our prior findings suggest that infants at this age do not represent observed grasps as object-directed. To support infants' ability to apprehend objects, we used velcro-bearing mittens, developed by Needham and her colleagues, which enable infants to pick up toys by swiping at them (Needham, Barrett, & Peterman, 2002). Needham and colleagues have found that with practice 3-month-old infants began to use the mittens in an apparently planful manner, and that this experience had enduring effects on infants' object exploration behaviors (Needham, Barrett, & Peterman, 2002).

We gave infants in the experimental group a few minutes of practice using the mittens. Small toys were placed on a surface in front of the infant, and he or she was allowed to swipe at the toys until one was picked up by the mitten. Infants generally found this game to be highly engaging. They swiped eagerly at the toys, and watched closely as their mittened hands moved the object. Then infants were tested in a habituation paradigm like the one depicted in Figure 1, except that the actor wore a mitten that matched the infants, and the toys were larger replicas of the ones the infant had acted on. Our goal was to maximize the similarity between the infants' experience and the observed events because similarity has been shown to facilitate mental comparison (Gentner & Medina, 1998). A control group of infants participated in the habituation paradigm before engaging in the mittens task.

As Needham and her colleagues had found, the mittens facilitated infants' manipulation of the toys. Infants spent a greater proportion of time in coordinated gaze and manual contact with the toys when they were wearing the mittens vs. when they were not. Critically, mittens experience also affected infants' responses to the habituation events. Infants in the experimental condition looked reliably longer on new-object trials than on new-side trials, that is, they attended to the relation between the actor and her goal. In contrast, infants in the control condition did not differentiate between the two kinds of test trials. Moreover, in the experimental condition infants' relative preference for the new-object event was correlated with the amount of coordinated gaze and manual contact on the toys while wearing mittens, but not with their total amount of visual contact with the toys, or their amount of coordinated gaze and manual contact when they were

given the chance to act on the toys without the mittens. Thus, infants' responses to the habituation events reflected the extent to which they had engaged in organized mittened actions on the toys rather than perceptual highlighting of the toys or individual differences in motor development.

In a later study, we replicated the finding that active mittens practice leads infants to represent observed mittened reaches as goal-directed (Woodward, 2004b). We also found that infants did not show this effect when they viewed a barehanded reach rather than a mittened reach. In other words, the few minutes of mittens practice infants received seemed to have relatively circumscribed effects. Infants did not readily generalize from the mittened action to other manual actions. This finding suggests that infants build relatively specific action representations to start. A question for future studies is whether infants would generalize more broadly as they gain expertise with an action.

Certainly, additional studies are needed to investigate the effects of acting on action perception across ages and across actions. Even so, these findings begin to support a developmental account in which infants' action knowledge is experience-driven, constrained by developmental progressions in the motor domain, and dependent on innate pathways for establishing mirroring systems. If this hypothesis is correct, as aspects of intentional structure emerge in the behavioral control systems of the infant, they may become available for action perception. The critical questions then become how (and whether) these effects on action perception contribute to subsequent conceptual development.

D. CONCLUSIONS: ORIGINS

The proposals outlined here highlight distinct hypotheses concerning the origins of intentional understanding and the relation between real-world knowledge and abstract concepts. One hypothesis is that core components of mature knowledge systems are innately specified in the form abstract principles (e.g., Premack, 1990; Gergely *et al.*, 1995; Csibra *et al.*, 1999). On this view, infants also accrue knowledge about real-world actions. This knowledge may come to inform infants' application of the innate principles in some circumstances, but it does not contribute to the formation of abstract knowledge about intentional action (see Gergely *et al.*, 1995; Kiraly *et al.*, 2003 for discussions).

A second hypothesis is that real-world action knowledge provides the developmental basis for more abstract conceptions of intentional action (Guajardo & Woodward, in press; Woodward, Sommerville, & Guajardo, 2001; see also Baldwin & Baird, 2001). Under this view, learning, cognitive comparison, and conceptual abstraction contribute fundamental structure to intentional understanding. Cognitive development in this domain may draw

heavily on social experiences, as well as the linking of information about ones own and others' actions (Carpenter, Akhtar, & Tomasello, 1998; Meltzoff, 2002; Carpendale & Lewis, 2004). On this account, the innate contributors to infants' action knowledge might not be abstract concepts, but instead shared neuro-cognitive representations for perceiving and producing actions.

Either kind of account could, in principle, explain the findings of relatively abstract expectations about goal-directed motions at the end of the first year of life. Although these findings are often taken as evidence for innate processing modules, they could also reflect the products of learning and abstraction. The two accounts differ in their predictions about the initial form of infants' action knowledge. As reviewed previously, much of the current evidence supports the conclusion that infants begin with relatively local representations of goal-directed action, only later showing signs of more abstract expectations. These findings are most consistent with the view that infants begin by tracking regularities in real-world actions, including their own, and from these regularities construct more abstract expectations about intentional actions. However, new findings are beginning to test the limits of this conclusion (e.g., Luo & Baillargeon, 2004). Further empirical investigations are needed to determine the scope and generality of young infants' action knowledge.

In addition, it may be useful to consider alternative models of the relation between abstract and real-world knowledge in development. One possibility is that these kinds of knowledge are independent contributors to infants' conceptual structure early in life. For important aspects of development, nature may provide a broad arsenal, including in this case, pattern detection systems, a rich database of observed real-world regularities, and the ability to relate representations of one's own actions to those of others. Each of these may emerge independently, and contribute to infants' abilities to represent the intentional structure of certain kinds of events. In this case, the open questions include how these components interact at different points in development. When abstract expectations contradict real-world regularities (e.g., when inanimate objects move in agent-like ways), on which basis will infants respond and why? Do these components remain independent throughout life, or do they become integrated with development?

An alternative possibility is suggested by considering discussions about the innate foundations of grammar. Infants might possess abstract, innate conceptions of intentional action, but these conceptions may only be expressed as infants discover the real-world cases that embody them. This is analogous to the hypothesis that children are born with innate universal grammar, which is only expressed once they have acquired the linking rules that specify how this grammar is embodied in their native language. If this were the case, then the findings that suggest initial specificity in infants' attributions of goal-directedness would reflect the gradual emergence of the "linking rules" rather than the gradual emergence of abstract knowledge. It has proven difficult to distinguish between

these possibilities in the case of language (e.g., Tomasello, 2001; Fisher, 2002), and similar debates may well arise in the domain of infants' action knowledge.

IV. Final Remarks

To understand the development of any system it is necessary to describe the states of the system at different points in time and the processes by which the system changes over time. The study of infant social cognition is relatively new, yet significant progress has been made toward the first of these goals, and first steps exist in the pursuit of the second.

As has been illustrated throughout this review, there are several points of broad consensus among researchers of infant intentional understanding, despite strong differences in theoretical assumptions and methodology. Converging evidence from across the field has shown that infants represent other people's actions in ways that are important for intentional understanding, that is, in terms of the relations between agents and their goals, agents and the objects of their attention, and subgoals and higher order plans. By the end of the first year of life, infants can flexibly interpret observed motions as goal-directed or not, or as directed at goals at differing hierarchical levels, based on contextual cues, and they track goals as the attributes of individual agents. These general conclusions about infant cognition dovetail with work on social cognition during the second year of life. By 18–24 months of age, children's responses to and learning from the actions of others is mediated by a rich system of intentional action knowledge. Elements of this system have now been traced to the first year of life.

There are also areas of heated debate, in particular those concerning the origins and initial development of infants' action knowledge. These issues currently focus much of the research on infant social cognition. In pursuing these issues, we should keep in mind an important insight from research on intentional action knowledge at later points in life: folk psychology is a system of interrelated concepts, and its application to real-world events involves structural principles at several levels of analysis (Baldwin & Baird, 2001). The questions for infancy research should be framed not in terms of when infants get "it", but instead in terms of the emergence of the system of concepts that becomes mature folk psychology. In later childhood, the folk psychological knowledge system emerges, at least in part, as a function of children's social experiences, including their conversations with parents, interactions with siblings and peers, and participation in a cultural context (see Dunn, 1999). It is reasonable to hypothesize that similar experiences contribute to infants' knowledge.

Infant cognition is often assumed to be qualitatively discontinuous from cognition in early childhood, but research in the social domain may reveal continuity, both in the environmental contributors to knowledge and in the nature

of knowledge itself. Indeed, findings from Wellman and his colleagues (in press) provide compelling support for this possibility. These researchers followed infants they had tested in a visual habituation paradigm (the Phillips, Wellman, and Spelke study, described previously), and tested these children at age 4 on an explicit theory of mind scale. Infants' visual responses at 12 months predicted their theory of mind performance at 4 years, independent of general intelligence. These findings are among the first to demonstrate continuity in a knowledge system from infancy to preschool, and they suggest that the social domain may provide an opportunity to develop an account that bridges the longstanding theoretical divide between infancy and the rest of life.

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