NAVIGATING THE SOCIAL WORLD

What Infants, Children, and Other Species Can Teach Us

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Infant Foundations of Intentional Understanding

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People are built for a social world. An impressive number of our perceptual and cognitive resources are dedicated to perceiving, making sense of, and responding to our social partners, including processes that support identifying and categorizing individuals, perceiving biological motion, responding empathically, rendering moral judgments, learning from social partners, and engaging in theory of mind reasoning. Among these processes, and foundational to many of them, is the ability to see others' movements as structured by intentions. When we watch others act, we see more than bodies in motion; we see agents whose actions are structured by intentions. Imagine a woman making her way through a crowded plaza, basket in hand, in order to reach a fruit vendor. We automatically view her movements as structured by goals (avoiding obstacles in her path, searching for the vendor, buying supplies for dinner, etc.). In viewing her actions in this way, we engage a specifically social analysis. If we were to see a piece of newspaper blow across the plaza taking a similarly complex path, we would not view its movements as intentional.

This way of viewing human action has been described in terms of "intentional relations" (Barresi & Moore, 1996) because actions are represented as structured by the relation between the agent and the object at which his or her actions are directed. A reaching hand is seen not just as an appendage in motion, but rather as an action directed at a goal object. A gaze shift is seen not just as the movement of eyes and head, but rather as an act of attention directed at a referent in the environment. Intentional relations can be understood at many levels of analysis, from the concrete (reaching for a lemon) to the abstract (making a tart, feeding one's guests, or preparing a celebration). The apprehension of intentional relations is deeply embedded in mature social perception, and it is also foundational for much of early social and cognitive development. As examples, not long after their first birthdays, infants recruit their understanding of others' intentional actions to inform their word learning (Baldwin & Moses, 2001; Tomasello, 1999), their imitative learning (Meltzoff, 1995), and their learning from others' emotional messages (Moses Baldwin, Rosicky, & Tidball, 2001). It is not surprising, then, that sensitivity to intentional relations can be traced back to early in infancy.

INFANTS' UNDERSTANDING OF GOAL-DIRECTED ACTION

By 6 months of age, infants view others' actions not simply as movements through space, but rather as actions structured by intentional relations. The first evidence for this conclusion came from visual habituation experiments. When infants were habituated to repeated examples of an action directed at a particular goal, they subsequently showed longer looking (a response to novelty) to events that disrupted the original relation between the agent and her goal than to events which preserved this relation while varying the physical details of the agent's movements (Woodward, 1998; see Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009 for a review). This pattern emerges early in the first year for simple instrumental actions, like reaching (Luo & Johnson, 2009; Sommerville, Woodward, & Needham, 2005; Woodward, 1998), and later in the first year for actions that relate agents to objects at a distance, like looking and pointing (Johnson, Ok, & Luo, 2007; Phillips, Wellman, & Spelke, 2002; Woodward, 2003), or reaching from afar (Brandone & Wellman, 2009), and for intentional relations that involve actions on intermediaries, such as tools (Hofer, Hauf, & Aschersleben, 2005; Sommerville et al., 2005; Sommerville, Hildebrand, & Crane, 2008).

Across these experiments, infants' encoding of intentional relations has been found to be selective for the well-formed actions of agents. When actions are ambiguous (Henderson & Woodward, 2011; Sommerville et al., 2005; Woodward, 1999) or agents are difficult to identify as animate (Biro & Leslie, 2007; Guajardo & Woodward, 2004; Hofer et al., 2005), infants do not respond selectively to the "goal" of the action. These ambiguous agents and actions direct infants' attention to the events in the same way that intentional actions do, but even so, infants do not respond to them as if they are goal directed (see Woodward, 1998, 2005 for discussions). Thus, it is not the low-level patterns of movement and contact that drive infants' responses to others' actions, but rather infants' analyses of these actions as goal directed.

Infants express their understanding of intentional relations with their hands as well as with their eyes. By 18 months, children show a robust propensity to selectively imitate the aspects of others' actions that are relevant to the actor's intentions (e.g., Meltzoff, 1995). The findings of visual habituation experiments with younger infants suggested that this tendency might be evident much earlier in life if the experimental procedures were made sensitive to the knowledge and abilities of younger infants. To investigate this question, Hamlin, Hallinan, and I (2008) showed 7-month-old infants events in which an experimenter reached toward one of two objects, and then gave infants the chance to choose between the two objects. We reasoned that if infants selectively reproduce the goal-relevant aspects of others' actions, they should systematically choose the experimenter's prior goal object, and this is what we found. Of course, infants might have selected the experimenter's goal for other reasons. In particular, the effects of the experimenter's reach in directing infants' attention to the toy might have led infants to choose that toy. To evaluate this possibility, we tested other groups of infants in the same procedure but showed them events in which the experimenter produced a novel or ambiguous action on the object (e.g., touching it with the back of her hand) or in which an inanimate object moved toward and contacted the toy (Gerson & Woodward, 2012; Hamlin et al., 2008; Mahajan & Woodward, 2009). These conditions entrained infants' attention in the same way that the reaching actions did, but infants responded to them differently: They chose randomly between the two toys. Thus, on parallel with their visual responses, infants' overt responses to others' goals are selective for the well-formed goal-directed actions of agents.

Infants' understanding of intentional relations goes beyond the perception of isolated events. To start, infants integrate information about a person's intentional actions over time. As examples, they generate rapid, on-line predictions about a person's reaching actions based on her prior goals (Cannon & Woodward, 2012), and they use a person's prior focus of attention to interpret her subsequent actions, for example, inferring that she is likely to reach for an object that she has previously attended to (Luo & Baillargeon, 2007; Phillips et al., 2002; Vaish & Woodward, 2010; see also Onishi & Baillargeon, 2005). In addition, infants use information about a person's actions in one context to interpret his actions in a new context. As examples, seeing an agent express a preference for an object influences infants' subsequent interpretation of his actions in a novel means-end sequence (Sommerville & Crane, 2009), seeing a person engage in a specific action with one object leads infants to expect she will seek out new objects on which that action can be performed (Song & Baillargeon, 2007), and seeing a person engage in a collaborative action informs infants' expectations about how she will later act on her own (Henderson & Woodward, 2011). Critically, infants understand that the individual person is the right unit of analysis for tracking intentional actions over time. By 9 months of age, infants know that an agent's actions provide information about her likely next actions, but not someone else's (Buresh & Woodward, 2007; Henderson & Woodward, 2012). Thus, although concepts of intention clearly continue to develop throughout early childhood, infants appreciate at least two critical aspects of intentions: They reside in the individual, and they serve to organize the individual's actions over time and across contexts.

ORIGINS

The research just reviewed shows that the infant mind, like the adult mind it will become, is built to make sense of the intentional structure of the social world. A pressing question for developmental psychologists is how the "building" takes place. Clearly, the ability to discern intentional structure in others' actions is essential for mature human social life, and, as discussed earlier, it is also critical for the acquisition of other foundational human abilities, including language and culture. When abilities that are critical for survival are found to emerge very early in life, it is often concluded that

their emergence reflects evolutionary processes but not learning or experience during ontogeny. Along these lines, a number of recent proposals consider infants' understanding of intentional action to be an expression of an inborn representational module that is triggered by the presence of certain visual cues, such as self-propelled movement (e.g., Biro & Leslie, 2007; Gergely & Csibra, 2003; Luo & Baillargeon, 2005). According to these proposals, infants respond selectively to the intentional relations in human action because human actions reliably exhibit the cues to trigger this inborn representation.

However, it is not the case that all critical, naturally selected abilities emerge independent of experience. In fact, developmental processes often exploit reliable learning opportunities to ensure the emergence of critical abilities. As examples, social imprinting, navigation, and birdsong are all clearly shaped by natural selection and important for survival, yet in many species experience and learning play an essential role in their development (Gallistel, Brown, Carey, Gelman, & Keil, 1991; Gottlieb, 1991; Marler, 1991). Thus, another possible explanation for the early emergence of infants' sensitivity to others' intentions is that this ability depends on early and reliable aspects of infants' experience. Consistent with this viewpoint, several recent proposals posit that infants' sensitivity to intentional relations is shaped by two kinds of experience: (1) producing, and refining, one's own intentional actions and (2) acting in coordination with social partners (Barresi & Moore, 1996; Meltzoff, 2007; Woodward et al., 2009). Each of these experiences is ubiquitous in human infancy and each could, in principle, provide the infant with information about the intentional structure of action. As detailed later, there is now clear evidence that the first of these contributes to infants' intentional understanding, and there is initial evidence for a role of the second.

In the first postnatal year, infants experience dramatic changes in their abilities to direct actions toward goals and objects of attention. At around 6 months, after months of practice, infants become able to launch efficient goal-directed reaches. At 9 to 12 months, infants begin to be able to orchestrate means-end actions, and during this same time they begin to produce referential gestures, like pointing. As infants become increasingly skilled at coordinating these actions, they gain insight into the intentional structure of those same actions in others. Infants begin to respond systematically to others' reaching, means-end, and referential actions at around the ages that these actions emerge in their own repertoires (Woodward et al., 2009). Furthermore, infants' action production and action understanding are correlated during periods when both are emerging (Brune & Woodward, 2007; Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Gredeback & Kochuhkova, 2010; Sommerville & Woodward, 2005; Woodward & Guajardo, 2002). For example, at 9 months, infants who themselves produce object-directed points also understand others' points in terms of the relation between the person and the object, whereas infants at this age who do not yet point do not (Brune & Woodward, 2007; Woodward & Guajardo, 2002; see also Liszkowski & Tomasello, 2011).

Critically, interventions that support infants' engagement in new goal-directed actions also support their ability to detect the intentional structure of those actions in others (Libertus & Needham, 2010; Sommerville & Woodward, 2005; Sommerville et al., 2008). For example, 3-month-old infants are too young to yet produce efficient goal-directed reaches, and they also fail to show sensitivity to others' reaching actions as goal directed. Training with Velcro-covered "sticky" mittens enables infants at this age to apprehend objects with their hands, and this training also leads infants to respond systematically to others' goal-directed actions in the habituation paradigm described earlier (Sommerville et al., 2005; see also Libertus & Needham, 2010). That is, learning to act causes changes in infants' understanding of others' actions.

Recent studies point to the potential neural correlates of the effects of acting on action understanding: Motor cortex activity occurs selectively when infants view other people producing actions that are within their own motor repertoire (Nystrom, 2008; Southgate, Johnson, El Karoui, & Csibra, 2010; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008). To illustrate, when infants who can crawl view films of other infants crawling, there is selective responding of the motor system, as indicated by shifts in chronic electroencephalographic activity measured over motor cortex, and this neural response is correlated with the observing infant's own degree of crawling experience (van Elk et al., 2008). These findings, which parallel similar findings in adults (e.g., Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005), suggest that neurocognitive systems for action production play a role in action

perception, and that as new modes of action are acquired, new neurocognitive resources become available for action perception. As yet, however, it is not known which aspects of action perception or action understanding are related to these patterns of neural activation in infants.

Learning from one's own actions is a useful first step, but it also has an important limitation. Social life requires understanding actions one has never performed. An infant viewing even the most mundane parental activities confronts many actions that are well beyond her own capacities. One way that infants could gain insight into novel actions is by analogy to actions they already understand. Analogical learning has been found to support children's, and infants', analysis of relational structure in a range of domains, including spatial relations (Christie & Gentner, 2010), causal relations in problem solving (Chen, Sanchez, & Campbell, 1997), and verb learning (Pruden, Shallcross, Hirsh-Pasek, & Golinkoff, 2008). It seems possible that this process could also support infants' detection of intentional relations in others' actions (see Barresi & Moore, 1996). By comparing a new action, for example, using tongs to pick up food, to a familiar one, for example, grasping objects, infants may detect the relational similarity between these two actions, and thus come to understand tong use as goal directed. The interactions that are common in infants' lives offer opportunities to engage in this kind of comparison. When infants coordinate actions with caretakers, their own actions are often aligned with those of the adult, for example, when the adult offers the infant an object or when the adult and infant jointly attend to an object. Under these conditions, comparison could support infants' understanding of the adult's actions.

Gerson and I (2012) tested this hypothesis by attempting to teach 7-month-old infants about a novel action, the use of a claw-shaped tool to grasp objects. Prior findings had shown that infants at this age do not spontaneously understand this action as goal directed. To assess infants' understanding of the tool action, we used the goal imitation procedure described earlier. In the critical condition, infants first engaged in joint actions involving the tool. The experimenter used the tool to hand the infant several toys, and this ensured that the infants' grasping actions co-occurred with the tool's action on the toys. This experience led infants to respond systematically in the imitation procedure, indicating that they now saw the tool action as goal directed. Infants in control conditions who interacted with the tool, or saw it move objects, but did not engage in joint action, responded randomly. Thus, the alignment of the infant's actions with the tool action seemed to be critical. By providing infants with the opportunity to compare the tool action with their own actions, joint action supported infants' understanding of this novel action. This laboratory demonstration highlights a process that could play a powerful role in enriching infants' understanding of others' actions because joint actions are common in infants' everyday lives.

CONCLUSIONS

Infants, like adults, experience a social world populated by intentional agents. Well before their first birthdays, infants see others' actions as structured by intentional relations. Moreover, infants view these intentional relations as organizers of people's actions over time and across situations. This foundational social worldview sets the stage for much of early social, cognitive, and linguistic development. When organized cognition is found to exist in young infants, this is often taken as evidence that learning is not needed to explain its emergence. However, as recent work has begun to highlight (Johnson, 2010; Woodward & Needham, 2009), this conclusion underestimates both the richness of the information present in infants' early experiences and the learning processes at infants' disposal. Recent findings highlight these factors in infants' developing ability to analyze others' intentions. The massive developments in infants' own actions during the first year yield action knowledge that seems to generalize readily to others' observed actions. Furthermore, in the context of everyday interactions, infants experience events in which their own actions are coordinated with those of adults, and this co-occurrence can support infants' detection of intentional relations in novel actions. Our findings, as well as other recent results (e.g., Pruden et al., 2008), suggest that the cognitive learning processes required to benefit from these learning opportunities operate during infancy. Taken together, these findings indicate that the human social worldview is structured, in no small part, by pervasive and early aspects of human experience.

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