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The link between action production and action processing in infancy.

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Introduction

Central to our ability to process and interpret the actions of others is the tendency to view action as directed toward goals or end states. Presented with a stream of ongoing behavior we construe single actions within the stream as directed toward objects, and interpret actions within a sequence as directed at higher-order goals or outcomes. Imagine an evening out at a local restaurant with a dinner companion. We readily perceive our social partner's reach toward and grasp of the fork as directed at the attaining a utensil, but also recognize this act as one step among many in enjoying a meal. The ability to construe action as directed toward proximate and ultimate goals is key to not only interpreting the actions of others, but also for predicting future actions based on past actions, for learning from and describing novel actions to others, and for categorizing action sequences in terms of the event representations to which they belong.

Empirical work has focused on adults' ability to build goal-centered event representations (for a review see Zacks & Tversky, 2001). When asked to describe naturalistic behavior adults rely on behavior episodes (e.g. driving to work) that correspond to events consisting of action parts (e.g., leaving the house, getting into the car, etc.; Barker & Wright, 1954). In laboratory tasks, adults readily identify goal-relevant action units in commonplace behavior. These action units are consistent both within and across individuals (e.g., Newtson & Engquist, 1976). Moreover, adults describe ongoing action to others with respect to its partonomic or hierarchical structure, parsing ongoing behavior both with respect to action-based goals (e.g., grasping a fork) and with respect to higher-order goals (e.g., eating a meal; Zacks, Tversky, & Iver, 2001). Goal–relevant actions are remembered more strongly than goal irrelevant actions in the context of text processing (Black & Bower, 1980) and prior segmentation of videotaped activity with respect to partonomic structure makes action content more memorable than unsegmented activity (Boltz, 1992b). These findings suggest that adults, a) create behavioral representations that parse activity at the level of action goals, and b) appreciate the organization of these action units and their relevance to the overarching or event goal.

Action processing in children

Recent work with children suggests that their ability to process human action shares many features with that of adults. Preschoolers spontaneously create hierarchically organized event schemas when asked about their everyday activities (e.g. Slackman, Hudson & Fivush, 1986). When asked to imitate the actions of another person preschoolers selectively reproduce the highest-order goal of the action (Bekkerring, Wohlschlager & Gattis, 2000). In addition, preschooler's and toddler's memories for action sequences often exclude actions that do not bear directly on the goal of the sequence (Travis, 1997). Ongoing research suggests that 4-year-olds' ability to recall the agent of a given action within a sequence is heavily influenced by the temporal proximity of the action to the goal of the sequence: agent recall decreases linearly with each step away from the goal (Sommerville & Hammond, in preparation). These findings suggest that children construct action representations that are, in many ways, similar to those of adults.

The state of action processing in infancy.

Findings on the relative sophistication of children's action processing and representation has sparked interest in the roots of this ability. In a landmark study, Meltzoff (1995) showed 18-month-old infants a human actor attempting to produce a target action, but failing. For instance, one of the sequences that toddlers viewed involved the actor trying to pull apart the ends of a miniature barbell. However, the actor's hands repeatedly slipped off of the barbell before he could complete the target action. Other infants watched the actor successfully complete the target action. When given the opportunity to act on the barbell, both groups of infants successfully reproduced the target action, despite the fact that the former group had never viewed this action before. These findings suggest that 18-month-olds readily construed the actor's actions (grasping the barbell, pulling at the ends, etc.) with respect to an overarching goal.

Other studies have investigated younger infants' ability to segment everyday activities into action units that are commensurate with those of adults. Baldwin, Baird, Saylor & Clark (2001) showed infants video clips of familiar action sequences, into which still frame pauses had been inserted. These pauses either preserved or disrupted the intentional structure of the activity. For instance, in some cases the pause occurred after the actor had picked up towel (preserving sequences), and in other cases the pause occurred in the midst of the actor reaching for the towel (disrupting sequences). Ten- and 11-month-old infants showed a novelty preference for disrupting sequences, indicating sensitivity to the intentional structure of the ongoing stream of behavior.

Recent research suggests that even young infants show goal-biased processing of simple, single actions. Five-month-old infants shown an event in which an actor reached for one of two toys showed selective attention to the relation between the actor and the object that she was grasping over other properties (such as spatial location and path of motion; Woodward, 1998). Several months later (by 12 months of age) infants also interpret attentional behaviors (such as goal-directed points and eye gaze) in terms of the objects that they are directed towards (Woodward, 2003; Woodward & Guarjardo, 2002). These findings suggest that over the first year of life infants begin to create action representations that highlight goal-relevant information.

In this chapter we discuss research that further explores the development of infants' action processing in the first year of life (Sommerville & Woodward, 2004; Sommerville, Woodward & Needham, 2004). In doing so we focus on two different time points that mark developmental achievements in goal processing: the ability to construe a simple reach and grasp as goal-directed and the ability to construe actions within a sequence as directed toward a higher-order goal. We discuss these achievements with respect to a key mechanism that we believe underlies infants’ ability to view the actions of others with respect to an underlying goal structure. Although it is likely the case that many innate and developing capacities contribute to infants’ ability to view action as goal-directed, we consider the rich information that infants’ own developing motor capabilities and action skills may play in their perception and interpretation of the actions of others.

<u>Action production and perception: birds of a feather?</u>

Recently evidence has been mounting to suggest that action production and perception are intimately related. Studies suggest that action observation, simulation and execution may rely on a common computational and neural code both in human and non-human primates (see Decety & Sommerville, 2004 for a review).

Behavioral research reveals that action production and observation share a common computational code (e.g., Hommel et al, 2001; Prinz, 1997). When asked to identify arrow directions presented on a monitor using already prepared left- and right-key responses, subjects' ability to perceive the direction of an arrow is reduced when the response required matches the arrow direction (Muessler & Hommel, 1997a). The findings from these spatial compatibility tasks suggest that interference occurs because action and perception try to simultaneously access the same representation. Interestingly, these spatial compatibility effects extend to situations in which the response is split across two participants (e.g., one participant responds to right-facing errors and the other to left-facing arrows), suggesting that other's actions are represented in a fashion similar to one's own (Sebanz, Knoblich & Prinz, 2003).

Prior motor observation also facilitates action production, suggesting that the perception of action primes a representation making it in turn more readily available to action. Viewing compatible motor responses prior to responding speeds action production, whereas viewing incompatible motor responses prior to responding slows action production (Brass, Bekkering & Prinz, 2001), and observing prehension primes subsequent execution (Castiello et al., 2002). Action production also affects action perception: perceptual judgments of arm movements affect subsequent motor learning (Hecht, Vogt, & Prinz, 2001).

Further evidence suggests that individuals may use their own action plans when observing the actions of others. In one study, individuals asked to predict the next marking in a handwriting sequence of another person benefited from having performed those sequences earlier (Knoblich, Seigerschmidt, Flach & Prinz, 2002). Moreover, individuals watching the actions of others appear to produce eye movements similar to those produced when they are performing similar actions themselves (Flannagan & Johansson, 2003).

Shared representation for action production and processing also exist at a neural level. In monkeys, the presence of "mirror neurons" which discharge during the performance and observation of a particular action suggests a system that links observed events to internally generated actions (e.g., Rizzolatti & Arbib, 1998; Rizzolatti & Fadiga, 1998). Research with human subjects provides evidence for a similar action observation/execution matching system in humans. Functional MRI studies indicate overlapping areas of activation during action observation, execution and simulation (e.g., Grezes & Decety, 2001). TMS studies suggest a selective increase in motor-evoked potentials during action observation (specific to muscles used to perform those actions; Fadiga, Fogassi, Pavesi & Rizzolatti, 1995) that closely follows that of movement execution (Gangitano et al., 2001). Similar to behavioral findings, some investigators report that the neural processes involved in preparing one's own action are also involved in predicting the future actions of others (Ramnani & Miall, 2003).

Taken together, the findings from behavioral and neural studies give teeth to the long-standing speculation that action production, simulation and understanding may be closely intertwined (e.g., Baldwin, 1897; Cooley, 1902; Goldman, 1989; Gordon, 1986; Harris, 1989; Heal, 1998; Mill, 1867). Indeed, many have suggested that observation/execution matching system may underlie our ability to understand the actions of others (e.g., Blakemore & Decety, 2001; Gallese & Goldman, 1998; Keysers & Perrett, 2004).

Action production as an engine in development

Researchers have speculated that the relation between action production and action understanding serves as a powerful engine in development. For instance, some investigators have argued that infants' understanding of others as intentional agents depends in large part upon their own newly emerging forms of intentionality in sensori-motor actions (e.g., Frye, 1991; Tomasello, 1999) or that imitation of others' actions allows infants to determine their intentions (Meltzoff & Moore, 1995b). Indeed, even neonates spontaneously imitate the actions of others (Meltzoff & Moore, 1977). These speculations and findings raise the possibility that action processing and production may be tightly interconnected from early in development. However, to date there are few studies that directly investigate the relation between action production and processing in infancy.

Regardless of the exact role that action production may play in action perception this perspective predicts that the interrelation between action perception and production should be apparent in at least two ways. First, natural variability in action production during periods of development should be related to variation in action perception. Second, providing infants with action experience should facilitate goal-directed action perception. To assess these claims, we have investigated the relation of infant action production and perception with two different age groups. We focused on the role of action experience on a) infants’ ability to construe simple actions (e.g., a reach and grasp) as goal-directed in 3.5 month-old infants (Sommerville, Woodward & Needham, 2004), and b) infants' ability to perceive action sequences as directed toward a higher-order goal in 10-month-old infants (Sommerville & Woodward, 2004). With respect to older infants we present work that examined the relation between naturally occurring variability in infants' action production and perception. With respect to younger infants, we present work that has explored the impact that providing infants with action experience has on action perception. Our research suggests that action production and action processing truly are birds of a feather: action production and perception are interwoven starting early in development (cf. Meltzoff, 2004).

The relation between natural variability in action production and action perception

Previous work suggests that 9 to 12 months of age marks a transitional time in infants' ability to spontaneously generate goal-directed action sequences (e.g., Bates, Carlson-Luden & Bretherton, 1980; Piaget, 1953). It is throughout this time that infants develop the ability to solve a variety of simple means end tasks (tasks which require producing an initial action in order to obtain a goal object), such as pulling a cloth to obtain a toy, opening a box to obtain a toy and pulling a string to get a toy. This ability has been considered a hallmark of intentional behavior as it requires the ability to separate a goal state from the means to achieving it (Piaget, 1953; Tomasello, 1999).

Over this same time period, infants demonstrate the ability to construe the action sequences of others in terms of their goal structure. By 12 months of age, infants selectively imitate the goal of a sequence but often exclude the means of the sequence when is not necessary for goal attainment (Carpenter, Call & Tomasello, 2004). Studies implementing infants' visual assessment of events have yielded similar findings. To illustrate, after 12-month-old infants watched an actor perform a box-opening sequence in which she opened a translucent box to grasp a toy inside, infants represented the actor's subsequent touch to the box lid as directed toward the toy inside the box rather than as directed toward the box lid itself (Woodward & Sommerville, 2000). Taken together with the action production findings, these results suggest that infants' ability to produce and perceive goal-directed action sequences share a similar developmental trajectory.

In one series of studies we investigated whether this shared developmental trajectory between action perception and production reflects a functional relation between the two abilities. Our goal was to develop action and perception measures involving the same sequence. We chose a cloth-pulling sequence (one in which a cloth that supports an out-of-reach toy can be pulled in order to obtain the toy) for three reasons. First, adults readily construe this action sequence as hierarchically organized: they view an individual's actions on the cloth as directed at the toy rather than at the cloth itself. Second, cloth-pulling sequences may be familiar to infants: they may have seen siblings pull a blanket in order to obtain a toy resting on top of it, or seen their parents pull a newspaper to retrieve their keys. Third, decades of literature on infant problem solving suggests that infants are able to solve a variety of simple means-end sequences by 1 year of age (Diamond, 1985; Piaget, 1953; Willatts, 1999). Our first goal was to test whether 12-month-old infants would respond to these observed sequences in the same way as the box-opening study. This then enabled us to investigate younger infants, who were likely to be transitional with respect to their comprehension of these sequences and their ability to produce them.

Infants were tested using a visual habituation paradigm. During this paradigm infants watched live events presented on a puppet stage and an on-line observer who was unaware of the particular events that the infant was viewing timed their looking to the outcome of these events (see Figure 1). During the habituation phase of the task, infants saw an actor sitting between two different colored cloths each of which supported a different toy. On each trial a screen was lowered and infants saw an actor pull a cloth that supported an out-of-reach toy, then grasp the toy once it came into reach. This action was performed once per trial, and infants were shown this event on multiple trials until their looking to the event declined to half its initial level. As such, infants saw a minimum of 6 and a maximum of 14 identical habituation trials. At this point all infants proceeded to the test phase of the study.

INSERT FIGURE 1 HERE

Prior to the test phase we switched the locations of the toys (so that each toy now sat on a different cloth than it initially had). This enabled us to show infants two new types of test events. In the **new toy** test events, the screen was lowered and infants saw the actor grasp the same cloth that she had on habituation trials that now supported a new toy. This event featured a disruption in the relation between the actor and her ultimate goal. In the **new cloth** test events, the screen was lowered and infants saw the actor grasp a new cloth (e.g. the cloth that supported the same toy that she had acted on during habituation trials). This event featured a disruption in the relation between the actor and the intermediary that she acted on. Infants saw these test events in alteration, 3 times each (for a total of 6 test trials). The prediction here was that if infants construed the actor's actions on the cloth as directed toward the toy (after having seen the completed cloth-pulling sequence), they should show a novelty preference for the **new toy** events. In contrast, if they misconstrued the actor's actions on the cloth as directed toward the cloth itself they may prefer the **new cloth** events.

Our findings provided further evidence that 12-month-old infants construe simple action sequences with respect to higher-order goals. Infants looked significantly longer to the new toy event, indicated that they represented the actor’s actions on the cloth as directed toward the toy. Thus, taken together with evidence suggesting that it is also by this age that infants can solve a range of means-end sequences (e.g. Piaget, 1953), these findings suggest that it is by 12 months of age that infants’ view both their own and others actions as directed toward higher-order goal.

These findings positioned us to investigate younger infants’ representations of the cloth-pulling sequence both in their own actions and the actions of others. We next sought to assess 10-month-olds’ interpretation of the cloth-pulling sequence. Based on previous work (Sommerville & Woodward, unpublished data), we suspected that 10-month-old infants would be transitional with respect to their ability to perceive the cloth-pulling sequence as directed toward the toy. Previous work also suggested that infants’ own means-end behavior is also transitional at this time (e.g., Piaget, 1953). To assess 10-month-old infants’ ability to construe another person’s cloth-pulling actions as directed toward a higher-order goal and their ability to solve a cloth-pulling sequence in their own actions in an apparently planful manner, we tested infants on an action production task (action task) and an action perception paradigm (habituation paradigm).

During the action task infants were given multiple opportunities to pull a cloth in order to obtain an out-of-reach toy. Infants' ability to solve this task was gauged by coding their solutions to the task. Specifically, we were interested in trials on which infants solved the task in ways that appeared planful, and clearly directed toward the ultimate goal of the sequence: obtaining the toy. Previous work suggests that cloth-pulling sequences can be solved by infants as young as 7 months, using strategies that can be best described as accidental (e.g. Willatts, 1990; 1999). For instance, infants might play with the cloth and inadvertently bring the toy within reach. As such, we considered as planful strategies those trials on which the infant looked at the toy, maintained focus on the toy while pulling the cloth, and quickly and immediately grasped the toy once it came into reach.

Infants also took part in the cloth-pulling habituation paradigm (see Figure 1). This paradigm was identical to that used with 12-month-old infants. These tasks were presented in a counterbalanced order such that half of the infants received the habituation paradigm first, whereas the other half of infants received the action task first.

We first assessed infants' group level performance on the action task and the habituation paradigm. We found that infants' ability to a) produce planful strategies to solve the action task, and b) perceive the actor's actions on the cloth as directed toward the toy in the habituation paradigm was variable. Specifically, on the action task infants produced planful strategies on just over half of all codable trials. In the habituation paradigm infants' looking to the two test events did not differ significantly: about half the infants looked longer on new goal trials and the other half looked longer on new side trials. These findings suggest, that unlike 12-month-olds, 10-month-old infants (as a group) do not systematically use goal-directed strategies to solve the cloth-pulling task in their own actions, nor do they systematically perceive the actions of another as goal-directed when that person performs a similar sequence. Thus 10 to 12 months of age marks a transition in infants' ability to perceive the goal-directedness of action sequences and to reliably produce goal-directed action sequences.

The variability that was naturally present in infants' action and habituation performance enabled us to investigate the relation between action and habituation performance at a more individual level. We first looked at the correlation between the frequency of planful strategies that infants produced on the action task (a measure of how goal-directed infants' own actions were) and the magnitude and consistency of their preference for the new toy test event (a measure of the extent to which infants were sensitive to the goal of another person's actions). This correlational analysis revealed that action task performance and habituation task performance were significantly related, even when controlling for age. Infants who showed a greater novelty reaction to test events that featured a disruption between the actor and the toy produced more planful strategies on the action task than infants who demonstrated a lesser preference (or the reverse preference).

In a second analysis we explored habituation task performance for the top and bottom performers on the action task. We categorized infants who performed in the top 25% with respect to how frequently they produced planful strategies "Planful infants". We categorized infants who scored in the bottom 25% with respect to how frequently they produced planful strategies "Non-planful infants". We then compared infants looking time preference on the habituation task as a function of action task performance. We found that both groups of infants showed systematic and opposite patterns in their looking times. Planful infants showed a significant preference for the new toy test events, whereas non-planful infants showed a significant preference for the new cloth test events. These findings suggest that planful infants understood that the actor's touch to the cloth was directed toward the ultimate goal of attaining the toy. In contrast, non-planful infants may have been focusing on the relation between the actor and the intermediary that she acted on: they may have construed her actions as directed toward the cloth itself.

These findings suggest that there is an intimate relation between the ability to process and produce at least one simple action sequence in infancy: pulling a cloth to get a toy. As such, our results provide some of the first empirical evidence for a link between action production and processing in infancy, and are consistent with the speculation that infants’ own action production may provide a powerful source of information for their ability to understand the actions of others (Meltzoff, 2004, Tomasello, 1999; Woodward, Sommerville & Guajardo, 2001). Such a perspective also predicts that providing infants with action experience may facilitate their ability to detect goals in the actions of others. In another line of studies we assessed the impact of an action experience intervention on young infants' action perception.

The impact of action production on action perception

Our findings point to a tight link between action production and perception by the end of the first year of life. However, because our results are correlational, they raise questions regarding the generality, directionality and nature of the relation between action processing and action production. With respect to generality, it is possible that a lurking third variable accounts for the observed relation between action production and processing (such as general intelligence or developmental level). Although our present results argue against this possibility (neither age nor habituation rate, a proxy for general intelligence, accounted for the relation between action processing and perception), it is difficult to rule this possibility out entirely. Furthermore, if the relation between action production and action processing reflects a causal one, the question arises as to whether developments in action processing lead to developments in action production, whether developments in action production lead to changes in action processing, or whether action processing and action production have a reciprocal influence on one another.

In a second line of studies we sought to assess the effect of providing infants with action experience on action perception and vice versa. To do so we tested younger infants using a habituation paradigm similar to that implemented by Woodward (1998). In this paradigm, during habituation trials, infants watch an actor reach for and grasp one of two toys sitting side by side on a stage. Once infants reach the habituation criteria the position of the toys are reversed and infants see events in which the actor reaches for a new toy (new toy event), in alternation with events in which the actor reaches for the same toys she did initially now in a new location (new side event). Adults seeing a similar event would be predicted to focus selectively on the relation between the actor and her goal object over other superficial changes of the event. Thus, this paradigm assesses infants' ability to construe a simple, single action (a reach and grasp) as goal-directed, by comparing looking times to the two test events.

Using this paradigm, Woodward (1998) demonstrated that it is by roughly 5 months of age that infants look significantly longer to the new toy event. In contrast, at 3 months of age infants attend equally to a change in the superficial perceptual properties of a reach and grasp (e.g., change in spatial location of reach) as to a change in the goal object of the reach (Sommerville, Woodward & Needham, 2004). Thus, this time period marks a transition in infants' ability to attend to the object- or goal-directedness of another person's reach.

Research on infants' ability to produce goal-directed reaches in their own actions reveals similar developmental trends. Infants' interactions with objects changes both qualitatively and quantitatively over the first 6 months of life. By 6 months of age infants show changes in exploratory behavior in the presence of objects, such as an increase in the amount of object manipulation (Baker, Adamson, Konner & Barr, 1990; Rochat, 1990). Over this same time frame infants develop the ability to reach proficiently under a variety of conditions. By 6 months infants can adjust their grasp to the size of an object (Clifton, Rochat, Litovsky & Perris, 1991; von Hofsten & Ronnqvist, 1988), reach under differing conditions of illumination (Clifton, Rochat, Robin & Berthier, 1994), adjust their body position when reaching for objects placed just beyond their grasp (Yonas & Hartman, 1993) and anticipate an object's trajectory (Robin, Berthier & Clifton, 1996).

This similarity in developmental trajectory led us to investigate whether providing infants with a reaching intervention would impact action perception. We first sought an intervention that would enable pre-reaching infants to successfully apprehend and move objects. To do so we utilized an action intervention task created by Needham, Barrett & Peterman (2002). In this task, pre-reaching infants were given play sessions with "sticky mittens" (mittens with palms that stuck to the edges of toys and allowed the infants to pick up the toys) that increased infants' object engagement and exploration strategies. We (Sommerville, Woodward & Needham, 2004; Woodward, Sommerville, Brune & Sootsman, in preparation) investigated the impact of sticky mittens experience on infants' perception of the goal-directedness of another person's reach and grasp.

To this end 3.5-month-old infants took part in an action intervention task (sticky mittens task) and a habituation paradigm (Sommerville et al., 2004). Half of the infants received the action intervention task prior to the habituation paradigm, and half of the infants received the tasks in the reverse order. Thus, we hoped to assess a) the impact of action intervention on action perception and b) the impact of action perception on action intervention.

During the action intervention task infants sat on their parent's lap in front of a white height adjustable table that was set at approximately waist height. For approximately 2 minutes infants were given the opportunity to look and interact with small toys barehanded. These toys (a ball and a teddy bear) were minature versions of the toys that were implemented in the habituation paradigm. During this initial 3 minutes, infants typically looked at and occasionally made contact with, the toys. The experimenter changed the position of the toys from time to time to ensure that infants were equally attentive to both toys.

After this initial period elapsed, the experimenter fitted a pair of small mittens on the infants. These mittens were made of a sheer fabric through which infants could see the back of their hands. The palm of the mittens was made of felt and covered with Velcro. Because the toys were also Velcro covered, the mittens would attach to the toys when infants made contact with a toy allowing infants to apprehend the toys. Infants were given the action intervention task for approximately 3 minutes. During this time the experimenter removed each toy from the mitten after it had been attached for several seconds, enabling the infant to have multiple opportunities to apprehend the toys. Again the experimenter changed the position of the toys from time to time to ensure that infants were equally attentive to both toys.

Infants also took part in the habituation paradigm (see Figure 2). This paradigm was identical to Woodward (1998), with the exception that the actor wore a white mitten identical to the one the infant wore during the action intervention task.

INSERT FIGURE 2 HERE

We first sought to establish whether we successfully intervened on infants' reaching experience. To do so we calculated the amount of time that infants spent in contact with the toy while also looking at the toy for both the barehanded and mittens phase of the action intervention. Infants spent a significantly greater proportion of time in coordinated eye gaze and manual contact with the toys with the mittens on than when they were off. These findings suggest that our intervention was indeed successful: infants interacted with the objects in a more clearly goal-directed manner as a result of the sticky mittens experience. Further analyses revealed that infants' action production was unaffected by whether they received the action intervention task first or whether they received the habituation paradigm first.

We next assessed the impact of action intervention on action perception by investigating infants' looking times to the test events. We predicted that the action intervention should help infants focus on the goal of another person's reach. As such, we predicted that infants who received the action task prior to the habituation task would show a significant preference for new object test trials over new side test trials, but that this effect would be absent for infants who received the tasks in the reverse order. Our findings bore out these predictions. Infants who received the action intervention prior to the habituation paradigm looked significantly longer at the new object events than at the new side events. In contrast, infants who received the tasks in the reverse order looked equally to both types of test events. Moreover, we conducted a series of correlational analyses examining the relation of infants' habituation response (their preference for the new object event) and various aspects of their mittened experience. These analyses revealed a selective relation between infants' overall amount of coordinated gaze and manual contact on objects while wearing the mittens and the extent of their preference for the new object events, indicating that the effects of action production on action perception were not reducible to perceptual highlighting of the toys or individual differences in motor development. Thus, action experience with the sticky mittens impacted infants' subsequent perception of the action of others.

Our findings suggest that experience producing goal-directed reaches facilitates infants' perception of the goal-directed reaches of others. In contrast, however, there was no evidence for an impact of action perception on action production. It is possible that action production and action perception exert a mutual influence on one another, but that this bi-directionality is difficult to measure in young infants. It may also be the case that the perceptual information that infants received in the habituation paradigm was not rich enough to influence their action production. Nevertheless, these results provide further evidence for a tight link between action perception and production. In the following section we consider the different ways in which action production may contribute to action perception.

Information gleaned from action production and the role of agency.

There is no doubt that multiple factors contribute to infants' ability to detect the goal structure of ongoing behavior. Our findings suggest that chief among these factors is infants' own experience as goal-directed agents (Sommerville & Woodward, 2004; Sommerville, Woodward, & Needham, 2004; Woodward, 2004). Infants' own action experience appears to exert a role in action perception from very early in life. Ongoing work is seeking to establish whether observational experience also plays a role in developing action perception, and whether that role is similar to or different from observational experience (Woodward, Sommerville, Brune and Buresh, in preparation). Self experience may exert an influence on action perception at a variety of different levels. Below we consider 3 possibilities.

Action experiences facilitates the detection of the behavioral manifestation of goals

Self experience may play a role in action perception by providing infants with exemplars of action from which cues to goal-directedness can be detected. Baldwin and colleagues (Baird & Baldwin, 2001; Baldwin et al., 2001) have argued that infants' ability to parse ongoing action into goal-relevant units may be based on their capacity to detect structural regularities in the stream of ongoing behavior that signal the completion of action goals or intentions. Indeed, bodily cues such as eye gaze, direction of motion and contact with object and release may signal an actor's intent. Such cues are present in both infants' own actions and the actions of others. Thus, infants' developing ability to produce particular actions may provide them with an increased number of exemplars from which to detect these behavioral cues. According to this account it is not critical that experience be self-produced: observing exemplars of another person acting may have a similar effect on action production. Although this possibility sounds like the simplest explanation of our data it is worth pointing out that gleaning structural information from one's own actions is not trivial. It requires the ability to take an objectified, unembodied view of the self's actions and also entails a perspective switch when applying this knowledge to the actions of others.

Action experience restructures representations of other's actions

Another possibility is that infants' developing ability to produce specific action sequences allows them to build action representations that relate particular actions to an end-state. In the case of the cloth-pulling sequence, this would entail building a representation that related the action of cloth pulling to the goal of toy attainment. Some authors have proposed that motor representations may help an individual monitor prospective actions on-line, and thus could function similarly in representations of others' actions (Rizzolatti et al., 2000). Indeed, Wilson & Knoblich (in press) have suggested that covert motor activation during action observation serves just this purpose: the internal simulation of perceived ongoing movements allows individuals to generate perceptual predictions.

Although representations of this nature could be similarly structured based on observational experience, self-produced experience could provide a privileged source of prospective organization. Infants' developing mastery of simple action sequences may necessitate attentional shifts to the goal of an action sequence. Consider acquiring a skill in adulthood, such as learning to serve a tennis ball. Initially a tennis novice may focus on each component of the serve at a time: bending her knees, throwing the ball up, pulling the racket back, with little attention to the overarching goal of hitting a winning serve. Over time, as mastery is attained over each component part, the player will allocate greater attention to hitting the ball, and directing it to the correct place on the court. A similar account may be applied to infants: as they come to solve the cloth-pulling sequence their attention may be increasingly focused toward the ultimate goal: attaining the toy. This re-organization of attention in infants' own action may then lead to a restructuring of action representations that are accessed when performing self actions and observing the actions of others.

Action experience yields introspective insight

A final possibility is that infants may glean important subjective information through their developing ability to produce a given action sequence. It is just this information that simulation theorists would argue forms the basis of our understanding of others' actions. For instance, the action of reaching for a highly desired object is accompanied by a particular intention: to obtain the toy. Under this view, infants are aware of this intention when they act on the cloth attempting to get the toy, and then apply this awareness to the behavior of others when they see others perform similar actions. Although such an account may appear untenable at first glance as it presumably requires that infants have awareness of their intention while acting and access to prior intentions, it is possible that such a simulation process may occur it an automatic and unconscious level rather than as a result of conscious cognitive effort (cf. Metzinger & Gallese, 2003)

Conclusions

The ability to construe human action as directed at objects and outcomes in the world is integral to mature social reasoning. The findings presented in this chapter suggest that by the end of the first year of life infants' processing of human action is in some ways commensurate with that of adults and older children. Specifically, over the first year of life infants develop the ability to perceive the goal structure of simple actions and action sequences. These findings raise interesting and important questions regarding the nature of infants' action representations and subsequent developments in infants' goal understanding.

Adults not only recognize goals as the physical end states of action sequences, but also can distinguish their own goals from those of others, understand goals as private attributes of individuals and construe goals as mental representations of outcomes that guide and motivate human behavior. Ongoing work is aimed at investigating when and how subsequent developments in goal understanding are achieved, and the functional relation of these more elaborate and sophisticated goal representations to early perceptual sensitivities to goals in the actions of others. One possibility is that a more abstract and mentalistic understanding of goals may emerge from these initial sensitivities. Infants' ability to structure action sequences with respect to a seen goal may provide the framework for redescriptions of human behavior with respect to unseen mental states.

Consistent with a burgeoning literature suggesting a common basis for both the production and perception of action, infants' own active experience contributes to their ability to view others as goal-directed agents. As such these findings provide some of the first empirical evidence for a link between action production and action processing in infancy. Thus, our results have implications for not only the ontogeny of shared representations, but impact theories of cognitive development more broadly. In demonstrating that infants **acquire** knowledge early in life based on their concrete experiences in the world we push the field beyond accounts that focus singularly on rich innate knowledge versus those that suggest that infants possess no cognitive abilities whatsoever. In addition, our findings provide points of continuity with classic theories of cognitive development as well as points of expansion and departure. Consistent with Piaget's claim regarding the primacy of sensori-motor actions in forming the bedrock of cognitive capacities, our findings document that motor skill acquisition helps to structure cognition. More specifically our results address the content of early action representations and the manner in which these action representations become structured at a microgenetic level.

Finally, our findings suggest continuity in action/perception mapping from infancy to adulthood. In doing so they raise fundamental and profound questions surrounding core issues in cognition. From the vantage point of infants' action representations we can begin to approach questions concerning the differences and similarities in procedural and declarative knowledge, the accessibility of representations to different systems and the role of active experience in conceptual acquisition and change. Assessing infants' understanding of others' behavior provides not only a snapshot of the developing mind of the child, but also a panorama of the very nature of cognition itself.

References

Baird, J. A., & Baldwin, D. A. (2001). Making sense of human behavior: Action parsing and intentional inference. In B. F. Malle, L. J. Moses & D. A. Baldwin (Eds.). *Intentions and intentionality: Foundations of social cognition*. (pp. 193-206). Cambridge, MA: The MIT Press.

Bakeman, R., Adamson, L. B., Konner, M. and Barr, R. G. (1990). Kung infancy: The social context of object exploration. *Child Development, 61*, 794-809.

Baldwin, D. A., Baird, J. A., Saylor, M. M., Clark, M. A. (2001). Infants parse dynamic action. *Child Development, 72,* 708-717

Baldwin, J. M. (1897). *Social and ethical interpretations in mental development: A study in social psychology*. New York: Macmillan.

Barker, R. G., & Wright, H. F. (1954). *Midwest and its' children: the psychological ecology of an American town*. Evanston, IL: Row, Peterson.

Bates, E., Carlson-Luden, V., & Bretherton, I. (1980). Perceptual aspects of tool using in infancy. *Infant Behavior and Development, 3,* 127-140.

Bekkerring, H., Wohlschlager, A. & Gattis, M. (2000). Imitation of gestures in children is goal-directed. *The Quarterly Journal of Experimental Psychology, 53*, 153-164.

Black, J. B., & Bower, G. H. (1980). Story understanding as problem solving. *Poetics, 9*, 223-250.

Blakemore, S. J. and Decety, J. (2001). From the perception of action to the understanding of intention. *Nature Reviews Neuroscience, 2,* 561-567.

Boltz, M. (1992b). Temporal accent structure and the remembering of filmed narratives. *Perception and Psychophysics, 57,* 1080-1096.

Brass, M., Bekkering, H., & Prinz, W. (2001). Movement observation affects movement execution in a simple response task. *Acta Psychologica*, *106*, 3-22.

Carpenter, M., Call, J. & Tomasello, M. (in press). Twelve- and 18-month-olds copy actions in terms of goals. *Developmental Science.*

Castiello, U., Lusher, D., Mari, M., Edwards, M. & Humphreys, G. W. (2002). Observing a human or a robotic hand grasping an object: differential priming effects, (pp. 315-333). In W. Prinz & B. Hommel (Eds.). *Common Mechanisms in Perception and Action: Attention and Performance XIX.* Oxford: Oxford University Press.

Clifton, R. K., Rochat, P., Litovsky, R. Y., and Perris, E. E. (1991). Object representation guides infants' reaching in the dark. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 323-329.

Clifton, R. K., Rochat, P., Robin, D. J., and Berthier, N. E. (1994). Multimodal perception in the control of infant reaching. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 876-886.

Cooley, C. H. (1902). *Human Nature and the Social Order.* New York: Scribner's.

Decety, J., & Sommerville, J.A. (in press). Motor cognition. In S. Kosslyn & E. Smith (Eds.) *Cognition: Mind and Brain*. New York: Prentice Hall.

Diamond, A. (1985). Development of the ability to use recall to guide action, as indicated by infants' performance on AB. *Child Development, 55,* 868-883.

Flanagan, J. R., & Johansson, R. S. (2003). Action plans used in action observation. *Nature, 424,* 769-771.

Frye, D. (1991). The origins of intention in infancy. In D. Frye and C. Moore (Eds). *Children's theories of mind: Mental states and social understanding.* (pp. 15-38) Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Gallese, V. and Goldman, A. (1998). Mirror neurons and the simulation theory of mind reading. *Trends in Cognitive Science, 12*, 493-501.

Goldman, A. (1989). Interpretation Psychologized. *Mind and Language 4*, 161-185.

Gordon, R. M. (1986). Folk psychology as simulation. *Mind and Language, 1*, 158-171.

Grezes, J. & Decety, J. (2001). Function anatomy of execution, mental simulation, observation and verb generation of actions: A meta-analysis. *Human Brain Mapping, 12*, 1-19.

Harris, P. (1989). *Children and Emotion*, Oxford: Blackwell Publishers.

Heal, J. (1998). Co-cognition and off-line simulation: Two ways of understanding the simulation approach. *Mind and Language, 13*, 477-498.

Hecht, H., Vogt, S., & Prinz, W. (2001). Motor learning enhances perceptual judgment: A case for action-perception transfer. *Psychological Research/Psychologische Forschung, 65,* 3-14.

Hommel, B., Muessler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral & Brain Sciences, 24,* 849-937.

Knoblich, G., Seigerschmidt, E., Flach, R., & Prinz, W. (2002). Authorship effects in the prediction of handwriting strokes: Evidence for action stimulation during action perception. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 55A,* 1027-1046.

Meltzoff, A. N. (1995). Understanding the intentions of others: Reenactments of intended acts by 18-month-old toddlers. *Developmental Psychology, 31,* 838-850.

Meltzoff, A. N. (2004). The case for developmental cognitive science: Theories of people and things. In G. Bremner & A. Slater (Eds). *Theories of Infant Development*. Malden, MA: Blackwell Publishers.

Meltzoff, A. N., and Moore, M. K. (1977). Imitation of facial and manual gestures by human neonates. *Science, 198,* 75-78.

Meltzoff, A. N. & Moore, M. K (1995b). Infants' understanding of people and things: from body imitation to folk psychology. In J. Bermúdez and N. Eilan (Eds). *The Body and the Self.* (pp. 43-69). Cambridge, MA: MIT Press.

Metzinger, T. & Gallese, V. (2003). The emergence of a shared action ontology: Building blocks for a theory. *Consciousness & Cognition: An International Journal,12,* 549-571

Mill, J. S. (1867). *Examination of Sir William Hamilton's Philosophy*. London: Longmans.

Muessler, J., & Hommel, B. (1997). Blindness to response-compatible stimuli. *Journal of Experimental Psychology: Human Perception & Performance, 23,* 861-872.

Needham, A., Barrett, T., & Peterman, K. (2002). A pick-me up for infants' exploratory skills: Early simulated experiences reaching for objects using 'sticky mittens' enhances young infants' exploration skills. *Infant Behavior & Development, 25*, 279-295.

Newtson, D. & Engquist, G. (1976). The perceptual organization of ongoing behavior. *Journal of Experimental Social Psychology, 28*, 28-38.

Piaget, J. (1953). *The origins of intelligence in the child.* London: Routledge & Kegan Paul.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9,* 129-154.

Ramnani, N. & Miall, C. (2004). A system in the human brain for predicting the actions of others. *Nature Neuroscience, 7,* 85-90.

Rizzolatti, G. & Arbib, M. A. (1998). Language within our grasp. *Trends in Neurosciences, 21*, 188-194.

Rizzolatti, G., & Fadiga, L. (1998). Grasping objects and grasping action meanings: the dual role of the monkey rostroventral premotor cortex (area F5). *Novartis Foundation Symposium, 218*, 81-95.

Rizzolatti, G., Fogassi, L. & Gallese, V. (2000). Cortical mechanisms subserving object grasping and action recognition: A new view on the cortical motor functions. In M. S. Gazzaniga (Ed.) *The new cognitive neurosciences*, 2nd Ed. (pp. 539-552). Cambridge, MA: MIT Press.

Robin, D. J., Berthier, N. E., and Clifton, R. K. (1996). Infant's predictive reaching for moving objects in the dark. *Developmental Psychology, 32,* 824-835.

Rochat, P. (1989). Object manipulation and exploration in 2- to 5-month olds. *Developmental Psychology, 25,* 871-884.

Sebanz, N., Knoblich, G., & Prinz, W. (2003). Representing others' actions: Just like one's own? *Cognition, 88,* B11-B21.

Slackman, E. A., Hudson, J. A., & Fivush, R. (1986). Actions, actors, link and goals: The structure of children's event representations. In K. Nelson (Ed.), *Event* *knowledge: Structure and function in development* (pp. 47-69). Hillsdale, NJ: Erlbaum.

Sommerville, J. A., & Hammond, A. J. (in progress). Getting the outside in:The effect of children's memory for "who" on children's memory for "what".

Sommerville, J. A., & Woodward, A. L. (unpublished data).

Sommerville, J. A., & Woodward, A. L. (in press). Pulling out the intentional structure of human action: The relation between action production and processing in infancy. *Cognition*

Sommerville, J. A., Woodward, A. L., & Needham, A. (in press). Action experience alters 3-month-old infants' perception of others' actions. *Cognition.*

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

Travis, L. L. (1997). Goal-based organization of event memory in toddlers. In P. W. van den Broek, P. J. Bauer & T. Bovig (Eds.), *Developmental spans in event comprehension and representation: Bridging fictional and actual events* (pp. 111-138). Mahwah, NJ: Erlbaum.

von Hoftsten, C., and Ronnqvist, L. (1988). Preparation for grasping an object: A developmental study. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 610-621.

Willatts, P. (1990). Development of problem-solving strategies in infancy. In. D.F. Bjorklund. *Children's strategies: Contemporary views of cognitive development*. (pp. 23-66). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc**.**

Willatts, P. (1999). Development of means-end behavior in young infants: Pulling a support to retrieve a distant object. *Developmental Psychology, 35*, 651-667.

Wilson, M. & Knoblich, G. (in press). The case for motor involvement in perceiving conspecifics. *Psychonomic Bulletin*.

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition, 69,* 1-34.

Woodward, A. L. (2003). Infants' developing understanding of the link between looker and object. *Developmental Science, 6*, 297-311.

Woodward, A. L. & Guarjardo, J. J. (2002). Infants' understanding of the point gesture as an object-directed action. *Cognitive Development, 17*, 1061-1084

Woodward, A. L. & Sommerville, J. A. (2000). Twelve-month-old infants interpret action in context. *Psychological Science, 11*, 73-77.

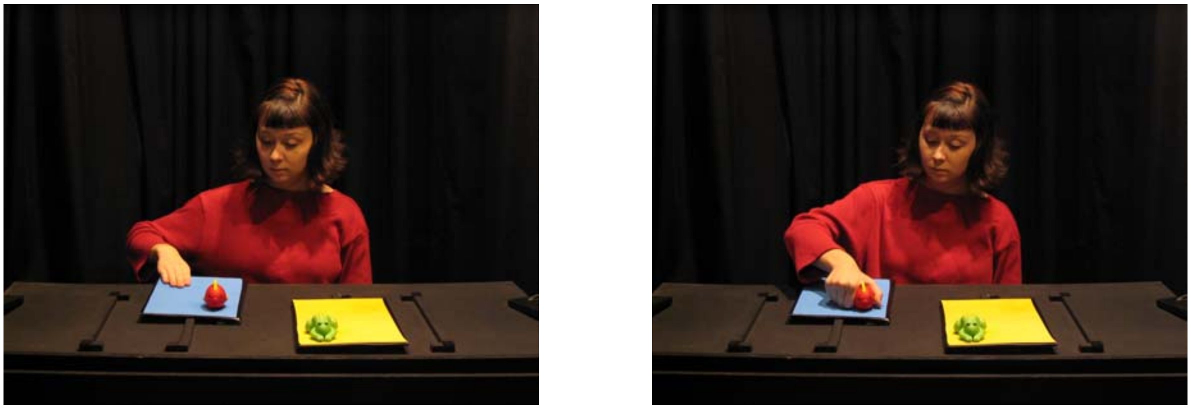
Woodward, A. L., Sommerville, J. A., & Guajardo, J. J. (2001). How infants make sense of intentional action. In B. F. Malle, L. J. Moses, & D. A. Baldwin (Eds.), *Intentions and intentionality: Foundations of social cognition* (pp. 149-169). Cambridge, MA: MIT Press.

Yonas, A, and Hartman, B (1993). Perceiving the affordance of contact in four- and five-month-old infants. *Child Development, 64*, 298-308.

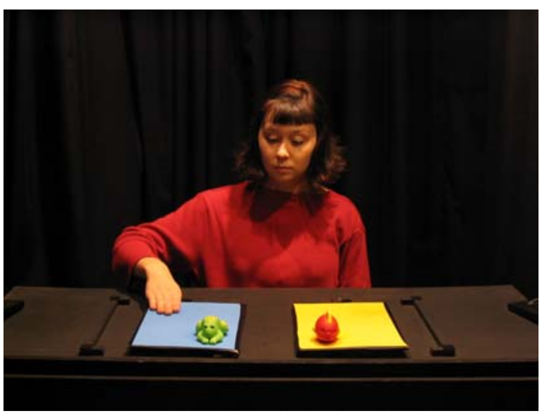
Zacks, J. M. & Tversky, B. (2001). Event structure in perception and conception. *Psychological Bulletin, 127*, 3-21.

Zacks, J. M., Tversky, B., & Iver, G. (2001). Perceiving, remembering, and communicating in events. *Journal of Experimental Psychology: General, 130*, 29-58.

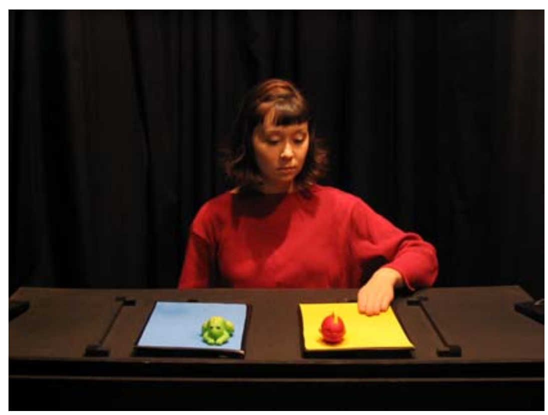
Figure 1: Cloth-pulling paradigm



Habituation Events



New toy event



New cloth event

Figure 2: Mittens paradigm

Habituation event

New toy event

New side event

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