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The joint role of trained, untrained, and observed actions at the origins of goal recognition

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ABSTRACT

Recent findings across a variety of domains reveal the benefits of self-produced experience on object exploration, object knowledge, attention, and action perception. The influence of active experience may be particularly important in infancy, when motor development is undergoing great changes. Despite the importance of self-produced experience, we know that infants and young children are eventually able to gain knowledge through purely observational experience. In the current work, three-month-old infants were given experience with object-directed actions in one of three forms and their recognition of the goal of grasping actions was then assessed in a habituation paradigm. All infants were given the chance to manually interact with the toys without assistance (a difficult task for most three-month-olds). Two of the three groups were then given additional experience with object-directed actions, either through active training (in which Velcro mittens helped infants act more efficiently) or observational training. Findings support the conclusion that self-produced experience is uniquely informative for action perception and suggest that individual differences in spontaneous motor activity may interact with observational experience to inform action perception early in life.

"Children learn as they play. Most importantly, children learn how to learn."

–O. Fred Donaldson

"Observation opens windows of knowledge around us."

–Sukan Ratnaker

Since Piaget (1954), the active role a child plays in creating experiences for him- or herself that drive development has been a topic of intense study in a variety of domains. This kind of experience has been hypothesized to be particularly critical in infancy, when the nature of self-produced action is undergoing marked developmental changes. For example, researchers have discovered links between the development of locomotion and a number of cognitive abilities, including emotional understanding (e.g., Campos, Bertenthal, & Kermoian, 1992), spatial memory (Bertenthal, Campos, & Barrett, 1984; Campos et al., 2000), and joint attention (Karasik, Tamis-Lamonda, & Adolph, 2011). Further, engagement in manual actions has been associated with developments in causal understanding (Rakison & Krogh, 2011), and object perception, and well as developments in object exploration (Libertus & Needham, 2010; Lobo & Galloway, 2013; Möhring & Frick, 2013; Oakes & Baumgartner, 2012).

In recent years, a number of findings have shown links between self-produced actions and the perception of others' actions, the object on which they are acting, and the relation between these during infancy. For example, Cannon, Woodward,

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Gredebäck, von Hofsten, and Turek (2011) found that the propensity of 12-month-old infants to perform containment actions (i.e., putting objects into a bucket) was related to their visual anticipation of the goal of this action when observed during an eyetracking experiment (i.e., looking to a bucket before an actor placed an object inside). Similarly, Gredeback and Kochukhova (2010) found that 25-month-old toddlers' puzzle-solving ability was related to their visual prediction of another's actions in putting together a puzzle. Other work indicates action-specific links between the stage of motor development and perception of others' action goals (e.g., shared attention and pointing: Brune & Woodward, 2007; means-end actions: Sommerville & Woodward, 2005; Sommerville, Hildebrand, & Crane, 2008).

The natural development of particular motor skills provides an ideal case in which to study relations between motor learning and action perception, as described in the correlational studies above. In order to determine the causal direction of these links, however, intervention studies are necessary. Before infants are able to produce particular motor acts on their own, they can be trained to produce these actions and the effect of these experimentally-induced experiences can be assessed in relation to action perception.

For example, three-month-old infants are not yet proficient at producing efficient object-directed reaches wherein they direct their actions toward an object and move or retrieve that object. Giving infants experience using Velcro mittens to play with Velcro covered toys at this age allows them to produce more efficient, object-directed reaches (see Needham, Barrett, & Peterman, 2002) and affects infants' perception of people, events, and the relations between an actor and an object on which he or she acts. Active training leads three- and four-month-old infants to attend more to faces (i.e., social agents, Libertus & Needham, 2010), perceive causality in motion events (Rakison & Krogh, 2011), and recognize the relation between an actor and her goal when she reaches for a particular object (Sommerville, Woodward, & Needham, 2005). Control conditions in each of these studies showed that infants this age responded differently to the agents, events, and actions when they did not receive active training.

Some researchers have suggested that developments in action perception and action production are linked by shared neuro-cognitive representations, sometimes called "mirror systems". This system is responsive both during the production and perception of motorically familiar goal-directed actions (Decety & Sommerville, 2003; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Gallese & Goldman, 1998; Lepage & Theoret, 2006). Though the majority of work concerning the mirror system in humans has been conducted with adults (e.g., Grezes & Decety, 2001; Rizzolatti & Craighero, 2004), increasing neurophysiological evidence indicates that this system may be in place in infancy, in that neural responses associated with action production are observed when infants view (or perceive) others' goal-directed actions or the effects of those actions (Marshall & Meltzoff, 2011; Paulus, Hunnius, van Elk, & Bekkering, 2012; Saby, Marshall, & Meltzoff, 2012; Shimada & Hiraki, 2006; Southgate, Johnson, Osborne, & Csibra, 2009; Southgate, Johnson, Karoui, & Csibra, 2010). For example, Paulus et al. (2012a) found that 8-month-old infants who learned a novel association between a sound and a familiar action (i.e., heard a sound when they shook an object) later showed motor activation when listening to this sound (without any visual input) and not to another sound (to which they were familiarized without the presence of an action).

Together, these findings indicate that the experience of producing actions influences early developments in action perception. However, these findings leave open questions concerning the aspects of the active experience that drive these effects. In particular, when infants engage in actions they also create for themselves observational experience watching those actions. It is not clear whether action production yields different kinds of developmental outcomes than does observational experience. Observational experience could shape action perception because it provides informative statistical evidence (e.g., when a hand touches an object, the object often moves) or because it may activate the mirror system on its own, with no need for the infant to engage in the action per se. In fact, in a follow-up to the above study conducted by Paulus et al. (2012a), it was found that observation of actions and their effects was sufficient to lead to motor activation in response to the effect. Other work, however, suggests that self-produced experience is influential, above and beyond the effects of observational experience.

Correlational work by van Elk, van Schie, Hunnius, and Bekkering (2008) provides indirect evidence that active experience is unique in its modulation of motor activity in infants, as measured with electroencephalography (EEG). In this work, van Elk et al. measured brain activity over motor regions while 15-month-old infants watched videos of other children walking and crawling. Infants' motor systems (as measured through suppression of mu rhythm over motor areas; see Marshall & Meltzoff, 2011; Vanderwert, Fox, & Ferrari, 2012) were more responsive when observing videos of infants crawling than walking. The authors suggested this was because crawling was an action with which infants at this age had more active experience. In support of this argument, the variation between infants in amount of experience walking (as measured in months since beginning to walk; independent of age) was related to the amount of motor activity detected while infants watched the videos of walking children. Young infants are exposed to many more individuals walking than crawling in their environment, but this observation of walking does not seem to drive motor activity in the brain, as the extent of motor activity was related to the amount of experience *producing* this action themselves. This suggests that self-produced experience uniquely modulated motor activity in the brain when later observing similar actions in this study. This is consistent with adult research on the mirror system suggesting that the system is particularly responsive to actions within one's motor repertoire and that motor expertise modulates motor activity in response to observed actions (e.g., Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005).

As noted before, correlational evidence alone does not provide direct information about the causal factors that give rise to correlated patterns. Several recent studies have addressed the differences between active and observational experience on perception of agents, objects, and actions through intervention studies. Libertus and Needham (2011) gave three-month-old