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Infants' motor simulation of observed actions is modulated by the visibility of the actor's body

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ABSTRACT

Previous research suggests that 9-month-old infants will develop a response bias in the A-not-B search paradigm after only observing an experimenter search for a hidden object on A-trials. In the current experiment, we tested whether infants would persist in making errors when only the hands-and-arms of the experimenter were visible. Three different conditions were included: (1) the experimenter was silent while hiding and finding the object, (2) the experimenter communicated with the infant via infant-directed speech, or (3) the body of the experimenter was visible during the training phase before his head and body were occluded during the test phase. Unlike previous studies, the results revealed that a significant proportion of infants searched correctly when the body of the experimenter was not visible, and only the combination of infant-directed speech and familiarization with a fully-specified body resulted in a majority of infants committing search errors. These results are interpreted as suggesting that the likelihood of infants committing search errors is dependent on their motor simulation of the experimenter's reaching. The strength of this simulation is graded by the similarity between the observed action and the motor representation.

1. Introduction

The perception and representation of others' actions is crucial for understanding our social world. Social neuroscientists suggest that there are brain mechanisms specialized for understanding observed actions, and some of these mechanisms are already present in young children (Decety & Sommerville, 2004; Frith & Frith, 2006; Saxe, Xiao, Kovacs, Perrett, & Kanwisher, 2004). One specific hypothesis is that observed actions are mapped directly to corresponding motor representations which are comprised of both movements and goals (Bertenthal, Longo, & Kosobud, 2006; Decety et al., 1997; Ferrari, Tramacere, Simpson, & Iriki, 2013). By matching the movements, observers activate a representation of the body part movement, but arguably without any cognitive importance. Alternatively, by matching the goal of an observed motor act, observers are able to understand what the actor is doing and why. Although much of the current research is focused on the goals of observed actions (Rizzolatti & Sinigaglia, 2010; Woodward & Gerson, 2014), the encoding of movements is important in its own right because it is necessary for imitation and learning (Heyes, 2011). In some cases, the observation of an action results in the execution of an overt movement, but typically the observation of an action activates the movement representation at only a subthreshold level and results in motor preparation or motor simulation (Longo & Bertenthal, 2009; Rizzolatti & Sinigaglia, 2010). The current study is concerned with how this motor simulation is modulated by the similarity between the observed action and the corresponding motor representation.

Recent electrophysiological evidence reveals that direct matching between the observation and motor representation of actions emerges during the infant's first year (Paulus, Hunnius, van Elk, & Bekkering, 2012; Saby, Meltzoff, & Marshall, 2013; Southgate, Johnson, El Karoui, & Csibra, 2010; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008). During this same developmental period, infants begin to understand others' goal-directed actions (Biro & Leslie, 2007; Csibra, Gergely, Bíró, Koós, & Brockbank, 1999; Király et al., 2003; Luo & Baillargeon, 2005; Woodward, 1998; Woodward & Sommerville, 2000). Consequently, some theorists suggest that there is a developmental relation between action understanding and the development of direct matching (Lepage & Théoret, 2007; Southgate, 2013; Woodward & Gerson, 2014). This view is supported by empirical evidence revealing a bidirectional

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relation between infants' motor experiences and their understanding of others' goal-directed actions (e.g., Cannon, Woodward, Gredeback, von Hofsten, & Turek, 2012; Daum, Prinz, & Aschersleben, 2011; Loucks & Sommerville, 2012; Sommerville, Woodward, & Needham, 2005).

Longo and Bertenthal (2006) pioneered one method for testing infants' motor simulation of the means or movements associated with actions by testing nine-month-old infants' with a modified version of Piaget's (1937/1954) A-not-B task. In the canonical A-not-B task, infants see an object hidden in one location, then actively search for it over a series of trials (i.e., A-trials); afterwards, they see the object displaced to a new location and search for it again (i.e., B-trial). Between eight- and 12-months of age, infants tend to search at the initial location on the B-trial, committing what is referred to as the A-not-B error (see Marcovitch & Zelazo, 1999 and Wellman, Cross, & Bartsch, 1986 for meta-analyses). Many accounts propose this error is at least partly attributable to the build-up of a motor bias over the course of the A-trials (Diamond, 1985, 1990; Smith, Thelen, Titzer, & McLin, 1999; Thelen, Schöner, Scheier, & Smith, 2001; Zelazo, Reznick, & Spinazzola, 1998). Longo and Bertenthal (2006) hypothesized that if infants map observed actions to their corresponding motor representations, they would commit the A-not-B error in an observational version of this task, because observing the experimenter's repeated reaches to A should activate the same motor representation as when reaching themselves. The results supported this prediction, but only for infants who observed the experimenter perform ipsilateral reaches (i.e., with the hand on the same side of the body midline as the hiding location), and not for those who observed contralateral reaches (i.e., reaches to the hiding location that crossed the body midline). Critically, this finding was consistent with the view that motor experience contributes to the development of motor simulation, because ipsilateral reaching begins to develop at four months of age, but contralateral reaching begins only two to three months later (Bruner, 1969; Gampe, Keitel, & Daum, 2015; Melzer, Prinz, & Daum, 2012; van Hof, van der Kamp, & Savelsbergh, 2002). As a consequence, the motor representation for ipsilateral reaching was more fully developed than the representation for contralateral reaching at nine months of age, and thus the motor simulation necessary to induce a response bias was apparently only strong enough for ipsilateral reaches.

Boyer, Pan, and Bertenthal (2011) followed-up these findings by testing whether nine-month-old infants' would commit the search error when observing a pair of mechanical claws in place of a human agent. The results revealed that infants did not motorically simulate actions performed by the claws, even if they had been familiarized with the experimenter handling, but not properly using, the claws. By contrast, if they were given observational experience with the claws' function in extending a person's reaches, they were more likely to motorically simulate the claw's actions during the testing phase. Similarly, Boyer and Bertenthal (2016) found that the hypothesized simulation of contralateral reaches during testing increased following a brief familiarization of the experimenter performing contralateral, but not ipsilateral, reaches. Taken together, these findings suggest that neither the observation of mechanical claws nor contralateral reaches is sufficiently similar to the infants' motor representation to activate the representation and elicit a response bias, unless they are first primed by recent actions performed by the experimenter.

To recap, infants' hypothesized motor simulation depends on the developmental status of the motor representation, as well as the similarity between the observed action and the infants' motor representation (Boyer & Bertenthal, 2016; Boyer et al., 2011; Longo & Bertenthal, 2006). These two factors contribute to the *representational strength* of the motor activation that occurs during action observation which explains why it is not always sufficient to elicit a response bias.

One crucial question raised by this proposal, but not yet empirically addressed, is whether nine-month-old infants' motor simulation requires the observation of a fully-specified and visible actor or whether the observation of only an actor's hands-and-arms is sufficient. There is considerable evidence that infants as young as six months of age understand goal-directed actions of human agents when just the reaching hand-and-arm is visible (e.g., Biro & Leslie, 2007; Woodward, 1998), and by seven months of age they infer some causal agency of hands (Saxe, Tzelnic, & Carey, 2007). One recent study even suggests that two-day-old infants discriminate between goal-directed and non-goal-directed reaches by a hand (Craighero, Leo, Umiltà, & Simion, 2011). Further evidence suggesting the sufficiency of the hands-and-arms is that nine-month old infants, though not six-month-old infants, expect a pair of moving hands to belong to a person rather than to an inanimate mannequin (Slaughter & Heron-Delaney, 2011), and both 12- and 18-month-old infants imitate hand actions as much as they do those of a fully-specified person (Slaughter & Corbett, 2007). Electrophysiological evidence also reveals decreased left hemisphere sensorimotor alpha activity (a measure of motor simulation) while nine-month-old infants observe actions performed by just a reaching hand (Southgate, Johnson, Osborne, & Csibra, 2009; Southgate et al., 2010).

In spite of the above evidence for motor simulation conducted with children younger than 12 months of age, all of these findings are based on electroencephalographic (EEG) or looking time paradigms, and do not require any reaching on the part of the infants. Also, the prevailing view in these studies is that motor representations support the analysis of others' actions based on coding the goals and not necessarily the movements of the actions (see Woodward & Gerson, 2014, for a review). By contrast, the actions observed in the A-not-B paradigm are encoded at both the level of movements, as well as at the level of goals (Bertenthal & Boyer, 2015). The motor representation necessary for coding the movements of observed actions may require greater stimulation, and may follow a more prolonged developmental progression than the representation necessary for coding the goals of actions. In particular, the cognitive control necessary for performing a reaching response is significantly greater than that required of a looking response (Berthier et al., 2001), which might explain why stronger motor activation is necessary in the A-not-B paradigm than in looking paradigms. Collectively, these considerations suggest that the observation of only an experimenter's hands-and-arms searching for the hidden object in the observational version of the A-not-B paradigm may not be adequate to activate a sufficiently strong motor representation necessary for inducing a response bias.

If this hypothesis is correct, then infants observing only the hands-and-arms hiding an object may not show any evidence of a search error, and instead search correctly. The goal of the current research was to test this hypothesis and also determine how the strength of the motor representation could be increased. As the motor representation is strengthened, we expect to observe a greater likelihood of infants committing the search error.

Nine-month-old infants were tested in one of three conditions. In the first condition, infants were tested with only the hands-and-arms of the experimenter visible; the remainder of his body and face were occluded and the experimenter was silent throughout the testing. In the second condition, the experimenter remained partially occluded, but communicated with the infant using infant-directed speech. Conceivably, the addition of this form of verbal communication would facilitate the mapping of the observed reaching to the corresponding motor representation, because infant-directed speech facilitates infants' understanding of others' actions and increases overt imitation (Brugger, Lariviere,