Brief Familiarization Primes Covert Imitation in 9-month-old Infants

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Abstract

Previous research reveals that 9-month-old infants who passively observe an experimenter search repeatedly for a toy in the Piagetian A-not-B error task covertly imitate these actions and manually search incorrectly when the toy is hidden in the B-location. Two experiments tested whether infants would also search incorrectly if the experimenter was replaced by a pair of mechanical claws or if the experimenter performed less familiar actions. Although infants did not commit the search error when tested directly without any familiarization to the novel actions, a significant majority of infants committed the search error following two minutes of familiarization with the actions performed on the A trials. These results converge to suggest that infants' brief experiences with observing actions will facilitate the activation of a corresponding motor representation. Furthermore, the specific process by which this facilitation occurs varies with the similarity between the observed action and its motor representation.

Keywords: Imitation; action observation; infancy; learning; motor simulation; A-not-B search error.

Introduction

During the first year of life, virtually every situation affords infants the opportunity to learn something new about themselves, other people or their surroundings. Much of this learning occurs through the observation of actions produced by others as well as the self. There is currently a range of opinions concerning the extent to which infants' action representations derive from experience vs. innately specified core knowledge (Csibra, Gergely, Bíró, Koós, & Brockbank, 1999; Woodward, 2009). Nevertheless, regardless of theoretical perspective, there is general consensus that infants' action representations are enriched and elaborated over the first year.

One intriguing explanation for how infants learn about goal-directed actions is that the perception and understanding of these actions is developmentally related to self-produced experience with these same actions (Rakison & Woodward, 2008). For example, it is now well documented that infants interpret actions as goal directed by five to six months of age, which is roughly the same age at which they begin to successfully reach for distal objects (Bertenthal & von Hofsten, 1998). Likewise, 9-month-old infants who understand the referent of a point are likely to also be able to point at distal objects (Brune & Woodward, 2007). At 10 months of age, infants who are capable of pulling a cloth to retrieve a toy are more likely to understand the means-end structure of a hierarchical action (Sommerville & Woodward, 2005). In spite of considerable evidence supporting a developmental relation between the perception and production of human actions, the vast majority of studies are correlative, and thus not informative about the underlying mechanisms.

In order to draw firmer conclusions about the causal relation between perception and production of goal-directed actions, it is necessary to experimentally manipulate either the perceptual experience or the motor experience of infants and test how this manipulation affects performance in the other domain. A few recent studies manipulating infants experience with reaching have now been conducted. Although 3-month-old infants are not yet capable of reaching and grasping distal objects, they can learn to retrieve these objects by swiping at them with 'sticky' mittens (Needham, Barret, & Peterman, 2002). When infants were given practice with these sticky mittens prior to testing their perception of others' mittened reaches as goal-directed, they interpreted the reaches as goal directed rather than as simple movements (Sommerville, Woodward, & Needham, 2005). By contrast infants given practice following the test did not interpret the reaches as goal directed. In a related study, Sommerville, Hidebrand, and Crane (2008) compared the effects of active vs. observational experience on 10-month-old infants' ability to identify the goal of a novel means-end task and reported that infants were more likely to understand the means-end task after receiving active as opposed to observational experience with the relevant action. These results suggest that active, but not passive, experience facilitates infants' learning about goal-directed actions.

It is difficult to know whether the preceding conclusion generalizes beyond the specific paradigms that were used. Hofer, Hauf & Aschersleben, (2005) tested 9- and 12-month-old infants and reported that they interpret actions performed by a mechanical claw as goal directed, but the younger age group was successful only after observing an experimenter demonstrate the operation of the claws. In this case, observational learning was sufficient to change infants' understanding of whether or not the claws acted in a goal-directed fashion. Moreover, Daum, Prinz, and Ascherleben (2009) report evidence that appears to directly challenge the findings of Sommerville et al. (2008). – The ability of infants to perform a hierarchically organized action was not predictive of their understanding of someone else performing the same action. These inconsistencies between studies are quite likely attributable to differences in the cognitive demands of the task (cf. Daum et al., 2009).

Based on all of the relevant evidence, the most parsimonious conclusion is that there is a bidirectional relation between the perception and production of actions (e.g., Hauf, 2008).

This proposal emerged originally with James's (1890) ideomotor theory and was elaborated more recently in Prinz's (1997) common coding theory. According to this theory, the perception and production of actions share common representational resources, and thus one process facilitates or interferes with the other when they occur close together in time (Hommel, Mussler, Aschersleben, & Prinz, 2001). The discovery of mirror neurons in nonhuman primates and homologous findings in humans showing that cortical areas active during action observation overlap with those that are active during execution of the same class of actions (see Rizzolatti & Craighero, 2004 for a review) offers further support for this theory. Behavioral studies reveal that action observation facilitates the execution of similar actions as well as the prediction of the effects or outcomes of those actions (Bertenthal & Longo, 2008). A number of authors theorize that a major function of the 'mirror neuron system' is to facilitate both imitation and action understanding (see Rizzolatti & Craighero, 2004). This facilitation is a product of simulating or 'covertly imitating' the observed actions in the motor cortex.

Although there is considerable electrophysiological, neuroimaging, and behavioral evidence showing that action observation activates matching motor representations in adults (see Heyes, in press for a review), the status of an observation-execution matching system in infants is much less clear. Some preliminary support for a matching system in infants is provided by evidence for mu rhythm desynchronization of infants' EEG responding to simple goal-directed actions but not to other movements (e.g., Lepage & Theoret, 2007). This desynchronization also occurs when subjects perform an action, which is why this response is considered evidence for an observation-execution matching system.

In one of the few behavioral studies relevant to this question, Longo and Bertenthal (2006) tested whether 9-month-old infants would show evidence of covert imitation following action observation. Recent accounts of the Piagetian A-not-B error emphasize the role of repeated reaching to the A location in causing perseverative reaching on the B trial. If infants simulate observed actions by activating corresponding motor representations, then they should show the perseverative search error not only following their active searching on the A trials, but also following the observation of someone else searching for the hidden toy on the A trials. In essence, we predicted that overt searching on the A trials is not necessary as long as the motor representation associated with this response is stimulated sufficiently to result in covert imitation of the observed search response.

Infants were tested in one of two conditions: (1) they recovered a toy hidden at location A, or (2) they observed an experimenter recover the toy. After three or six trials, the toy was hidden at location B, and infants in both conditions perseverated in reaching to A, demonstrating that active search by the infant is not necessary for the A-not-B error. Interestingly, contralateral reaching (i.e., a reach that crosses the midline of the body) is not as common as ipsilateral reaching (i.e., a reach on the same side of the body as the object) in 9-month-old infants (Bruner, 1969) suggesting that the corresponding motor representation is not as well developed. Consistent with this hypothesis, infants showed an ipsilateral bias when reaching, and only showed a systematic search error after observing ipsilateral, but not contralateral, reaching by the experimenter.

Taken together, the results from these experiments revealed that infants demonstrated (1) covert imitation by mapping or mirroring the representation of the perceived action to their motor system (2) if, and only if, the perceived action overlapped with a sufficiently developed motor representation. This latter finding was especially significant because it ruled out the possibility that search errors were simply a function of passively observing infants directing their attention primarily to the A location on the A trials, which subsequently biased them to attend to the same location on the B trial. Infants who observed either ipsilateral or contralateral searches by the experimenter would have still directed the same amount of attention to the A location on the A trials. Nevertheless, only the infants who observed the experimenter search with his ipsilateral hand showed the A-not-B search error.

The current research was designed to further explore the prerequisite conditions for stimulating covert imitation. Actions are coded at multiple, hierarchically nested levels of representation, ranging from activation of specific muscles to direction of movement to goal completion (Jeannerod, 1997). Both infants and adults are able to imitate actions at either the level of their movements or goals. Recent research suggests that observers are more likely to represent the goals than the movements of perceived actions, but this bias can be shifted by directing the observer's attention to the movements through various priming techniques (Longo, Kosobud, & Bertenthal, 2008). In the current research, we conducted two new experiments in which we primed infants' motor representations prior to testing them in the A-not-B search paradigm. The priming consisted of isolating the specific search action that infants would observe during testing and repeatedly demonstrating this action during a prior familiarization period. We hypothesized that infants would be more likely to stimulate their own motor representation of reaching for the hidden object if their attention was focused on the specific movements performed by the agent searching for the object.

Experiment 1: Testing Infants with Mechanical Claws

The first series of three experiments was conducted using the same procedure used by Longo and Bertenthal (2006), except that a pair of mechanical claws hid and retrieved the toy. The operator of the claws was completely

hidden behind a screen in Experiment 1a and only his hands were visible in Experiments 1b and 1c. In Experiments 1b and 1c, infants were briefly familiarized with the claws for two minutes before the testing was conducted (see below). Thirty 9-month-old infants were tested in each of the three experiments.

Although these mechanical claws simulated the actions of the experimenter's hands, it was questionable whether infants would covertly imitate the actions of the claws because it is sometimes claimed that the stimulation of motor representations is limited to the observation of biological motions. In spite of this assertion, recent studies testing action perception with non-biological motions often report activation of motor representations, albeit to a lesser extent than with biological motions (Heyes, in press).

Apparatus and Procedure

During the experiment infants were seated on their caregiver's lap and faced a table supporting a cardboard box containing one or two covered hiding wells. The experimenter was positioned on the other side of the table but screened from the infant. Two claws were visible below a curtain suspended above the cardboard box. The claws were controlled by the experimenter who remained invisible throughout the experiment (see Figure 1). Four training trials with a central hiding well were administered following the procedures of Longo and Bertenthal (2006) except that only the claws were visible to the infants. After training was completed, a new hiding apparatus consisting of two covered wells located to the left and right of midline was placed on the table in front of the infants. They were presented with six identical trials in which a toy was hidden in the same location each time.

On each trial, the experimenter extended the claws from behind the curtain, grasped the toy located between the wells, rattled it, placed it in the A well and covered it with the lid, retracted the claws, waited three-seconds, then retrieved the toy and placed it between the wells. After the six A-trials were completed, the experimenter hid the toy in the B location, retracted the claws and waited three-seconds, then slid the apparatus forward using the claws and allowed the infant to search. The experimenter consistently grasped the toy with the claw operated by his right hand and grasped the lid with the claw operated by his left hand; the position of the A hiding location was counterbalanced across infants. The sessions were videotaped and coded offline.

Dependent Measures

The primary measure of interest was whether infants searched incorrectly in the A location or correctly in the B location on the final trial when the toy was hidden in the B location. In order to ensure that infants were not biased to search in the A or B location because of any attempts to reach for the toy on A-trials, two observers coded the number of reaches executed by infants on the A trials from the videotapes of the sessions (the average number of reaches per infant was well below one across experiments).

These observers also coded infant's looking to both the A- and B-locations throughout the experiment to ensure that search performance could not be explained by visual attention alone. The results revealed that visual attention to the A and B hiding locations did not differ across experiments even though search performance did. Accordingly, visual attention was not sufficient to explain the observed search performance and will not be discussed further.

Figure 1: Photo of an infant observing the claws during testing of the A-not-B search error.

Results and Discussion

In Experiment 1a, only 12 of the 30 infants (40%) searched incorrectly on the B trial (see Figure 2). By contrast, Longo and Bertenthal (2006) reported that a significant majority of infants (70%) committed the perseverative search error after observing an experimenter manually hide and retrieve an object. Although this result is consistent with an observation-execution matching system being limited to biological motions, it is also possible that infants did not sufficiently encode the actions of the claws because they were unfamiliar. As a consequence, the claws, themselves, attracted either greater attention because they were novel or less attention because they created anxiety in some infants (Hofer et al., 2005). In order to check this possibility, Experiment 1b began with a brief familiarization phase in which the experimenter played on the floor with the claws and other toys for two minutes in front of the infants. This familiarization period ensured that the claws would be somewhat more familiar by the time of the experiment, but the results were still no different than the first experiment. The number of infants searching incorrectly on the B trial was only 14 of 30 (46.7%; see Figure 2).

In Experiment 1c, infants were familiarized with the operation of the mechanical claws to ensure that they perceived them as a means to an end (i.e., an instrument or device to retrieve other objects) rather than merely as another object. During a two minute familiarization period, the experimenter demonstrated how the claws operated by

rolling toys away and then retrieving them with the claws. Unlike the results from the first two experiments, 20 of the 30 infants (66.7%) searched incorrectly in the A-location on the B trial (see Figure 2). This result is significantly greater than chance ($p = .05$), and thus suggests that infants covertly imitated the actions of the claws on the A trials. If the results of this experiment are compared to the results from Experiment 1a, the difference is statistically significant, $\chi^2 (1, 60) = 4.29$, $p = .04$; a comparison between these results and those of Experiment 1b were not significant but showed a trend in the same direction, $\chi^2 (1, 60) = 2.44$, $p = .11$.
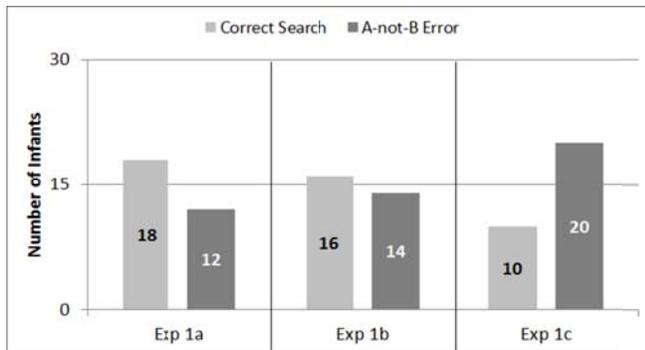

Figure 2. Number of infants searching correctly and incorrectly in each of the three experiments.

Taken together, the results from these three experiments reveal that infants' motor representations of another's actions can be primed by observational learning. After a brief familiarization with the function of the claws, infants' were more likely to activate a motor representation of the claws' actions. If infants only visually encoded the search behaviors of the claws during the A trials, then there would be no reason for them to commit the error, because this response is specifically attributable to repeated overt or covert reaching to the same location. Although other interpretations for incorrect search behavior emphasize the history of the infant's attention to the A location or the pedagogical stance introduced during the testing (Csibra & Gergely, 2009), these theories cannot adequately explain why there is a search error following passive observation. Thus, the most likely explanation for this error is that a motor representation is stimulated during the passive observation of the claws searching for the toy.

Interestingly, infants' mapping the observed search behavior by the claws to their motor representation is somewhat at odds with previous neuroimaging and behavioral studies showing greater responsiveness to biological than non-biological movements (Bertenthal & Longo, 2008). It is important to note, however, that these findings represent relative and not absolute differences. Most of the previous studies report that the observation of non-biological movements does activate the motor system, but just not as much as the observation of biological movements. In other words, the difference in activation of the motor system as a function of biological vs. non-

biological movements is not all-or-none. Moreover, Ferrari, Rozzi, and Fogassi (2005) report the emergence of tool responding mirror neurons in nonhuman primates after two months of observational experience with tools (e.g., a stick or pliers). These findings suggest that the matching mechanism can reach a considerable degree of abstraction with sufficient experience. It is hypothesized that contextual and kinematic similarities between the goal-directed actions of the hand and the tool contribute to the development of these neurons through the processes of associative learning and generalization.

Also, as discussed previously, Hofer et al. (2005) reported that 12-month-old infants interpreted the behavior of mechanical claws as goal directed and 9-month-old infants interpreted these claws similarly following a demonstration of their operation. This latter finding suggests that 9-month-old infants may have been in a transitional state with regard to the mapping of the actions of the claws to their own motor representations. It also begs the question as to whether the main reason that the familiarization phase primed infants' responses to the A location was because the claws were initially unfamiliar and perceived as mere objects rather than as effectors that could serve as means to an end. Once infants perceived the claws as effectors and focused on their specific movements as well as goals, they were more likely to map these actions to a (means-ends) motor representation consisting of both movements and goals that increased in strength over the six A trials.

Experiment 2: Testing infants with Contralateral Reaching

In order to assess whether priming infants' motor representations was specific to learning the function (i.e., the means-ends relations) of the claws during a brief familiarization, we conducted a second series of experiments to assess whether infants' motor representations of contralateral reaches could be strengthened with a familiarization period. Recall that Longo and Bertenthal (2006) reported that the search error on the B trial was observed only after the experimenter searched with an ipsilateral reach on the A trials because the motor representation for a contralateral reach was not sufficiently developed by 9 months of age. In Experiment 2a, infants observed the experimenter reach exclusively with his contralateral hand during a two minute familiarization period. In Experiment 2b, infants observed only ipsilateral reaching during the familiarization period. If one or both of these familiarization experiences increased the salience of the contralateral hand reaching, we hypothesized that the repeated observation of the experimenter searching on the A trials would result in a stronger motor representation and bias infants to search incorrectly on the B trial.

Procedure

Experiments 2a and 2b each included 30 9-month-old infants. The testing of the A-not-B search error followed

the same procedure used in Experiment 1, except that the experimenter was visible and always hid the object and searched for it with his contralateral hand. The two minute familiarization period in Experiment 2a was designed to increase the salience of contralateral reaching by the experimenter. Infants were seated on the floor opposite the experimenter who repeatedly reached only with his contralateral hand for toys located in one of two piles to his left or right. In Experiment 2b, infants were familiarized with the experimenter reaching repeatedly with only his ipsilateral hand. This manipulation was designed to test whether priming the motor representation of a contralateral reach was specific to infants observing the experimenter reach consistently with his contralateral hand or was more generally a function of infants observing the experimenter reach repeatedly in a goal-directed fashion.

Results and Discussion

Longo and Bertenthal (2006) reported previously that approximately 50% of 9-month-old infants search incorrectly after observing an experimenter search with his contralateral hand on the A trials. By contrast, 20 of the 30 infants (66.7%) searched incorrectly in the A-location on the B trial in Experiment 2a (see Figure 3). This result is significantly greater than chance ($p < .05$, Binomial test), and suggests that infants not only visually encoded that the experimenter reached with his contralateral hand, but they also covertly imitated this behavior by activating a motor representation.

In Experiment 2b, the results revealed that infants' search performance was no different than chance (16 of 30 infants searched incorrectly; see Figure 3). Thus, there is currently no evidence to suggest that simply priming infants with repeated reaching is sufficient to specifically stimulate a motor representation of a contralateral reach.
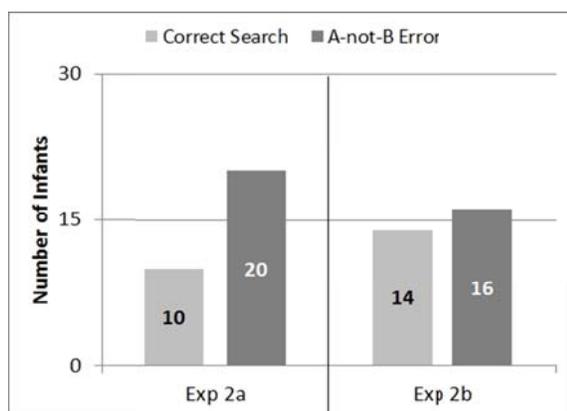

Figure 3. Number of infants searching correctly and incorrectly in each of the two experiments.

General Discussion

The results from these experiments converge to suggest that infants' brief experiences observing actions will be represented not only by their visual system, but by their motor system as well. These representations become more accessible when preceded by the observation of a very salient demonstration of the action, which appears to prime the motor representation. Little is currently known about the time course of this priming or how it contributes to more permanent learning, but it is a subject of ongoing research. Likewise, the necessary similarity between the observed action and its motor representation remains unclear, although the current research suggests that the matching process is modulated by the task.

The results from Experiment 1 suggest that the mapping process between an action perception and its motor representation is more abstract than sometimes acknowledged by theorists advocating for a mirror neuron system. We conjecture that infants learned very quickly to generalize goal-directed reaching actions to the claws, and thus mapped the observed actions of the claws to the same corresponding motor representations associated with reaching. As previously mentioned, this generalization is also hypothesized to occur in the development of tool responding mirror neurons in macaques. One significant difference between the two species is that this generalization requires two months of experience in macaques while it occurs after only two minutes of experience in human infants. This difference suggests that human infants are much better prepared for this experience either because the mapping mechanism between the visual description and motor representation of the action is already more abstract or a different mechanism is available in humans.

Unlike the results from Experiment 1 suggesting that the matching mechanism generalized across different movements, Experiment 2 suggests a mapping mechanism that is less abstract and tuned to specific movements. One hypothesis for this difference is that infants mapped the observed reaching by the experimenter to a specific motor representation describing either a contralateral or ipsilateral reach. The representation for the contralateral reach is less developed and thus does not elicit sufficient covert imitation unless it is primed during the preceding familiarization period.

One caveat concerning the preceding interpretation is that perseverative reaching on the B trial is only a proxy for covert imitation, but this measure is at best an indirect assessment of the motor representation. More convincing evidence for this hypothesis must await a more direct assessment of the change in the motor representation. One possibility would be to measure mu desynchronization in the EEG response of infants during the administration of the A-not-B error task.

Although it is premature to reach any firm conclusions regarding the mechanisms responsible for greater perseveration following the familiarization period, the evidence from the two experiments is consistent with the hypothesis that the brief demonstrations prior to testing focused infants' attention on the specific movements as well as goals of the agents in these experiments. This focus on the means-ends relations no doubt benefits from the

experimenter's repertoire of social cues directing the infant to attend to the relevant goal-directed action (Corkum & Moore, 1995). We conjecture that the demonstrations were effective specifically because the experimenter assumed a pedagogical stance that exploited ostensive communicative cues, such as direct eye contact, infant-directed speech, and contingent reactivity to the infant. According to Csibra & Gergely (2009), natural pedagogy represents a special type of social learning that facilitates learning by directing the observer's attention to the important action elements. In the current experiments, the demonstrations during the familiarization phase were designed to specifically focus attention on the repeatable goal-directed actions, and were apparently successful in that infants were more likely to search incorrectly on the B trial following the demonstration of the relevant action.

Although we hypothesize that these demonstrations were successful because they embodied the key features of natural pedagogy, the relevance of this form of learning remains an empirical question that must also await further testing. Conceivably, a demonstration without the ostensive communicative cues or perhaps even without a social agent would suffice for priming infants to activate their motor representations for reaching. Regardless of the specific process responsible for priming infants' motor representations, it is important to consider that the focusing of infants' attention on the specific movements of an action modulates how the action is represented by the motor system.

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