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Brief article

Action experience alters 3-month-old infants' perception of others' actions

Jessica A. Sommerville[a,*], Amanda L. Woodward[b], Amy Needham[c]

[a]*Department of Psychology and Institute for Learning and Brain Sciences, University of Washington, Seattle, Washington, DC, USA*
[b]*Department of Psychology, The University of Chicago, Chicago, IL, USA*
[c]*Department of Psychological and Brain Sciences, Duke University, Durham, NC, USA*

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Abstract

An intervention facilitated 3-month-old infants' apprehension of objects either prior to (reach first), or after (watch first) viewing another person grasp similar objects in a visual habituation procedure. Action experience facilitated action perception: reach-first infants focused on the relation between the actor and her goal, but watch-first infants did not. Infants' sensitivity to the actor's goal was correlated with their engagement in object-directed contact with the toys. These findings indicate that infants can rapidly form goal-based action representations and suggest a developmental link between infants' goal directed actions and their ability to detect goals in the actions of others.

Keywords: Action/perception; Intentional structure; Infant cognitive development

1. Introduction

The tendency to view action in terms of its underlying goal structure is pervasive in mature cognition. Adults and children organize their event memories around action goals (Newtson & Engquist, 1976; Zacks & Tversky, 2001), information about a protagonist's goals guides narrative construction and interpretation (Black & Bower, 1980; Trabasso,

* Corresponding author.
E-mail address: sommej@u.washington.edu (J.A. Sommerville).

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Stein, Rodkin, Munger, & Baugh, 1992), and goals and intentions serve as both explanatory constructs and predictive cues for describing our own and others' behavior (D'Andrade, 1987; Wellman, 1990). Sensitivity to the goal structure of action also plays a powerful role in mediating learning across a variety of domains. Goal understanding guides early word learning (Baldwin & Moses, 2001; Woodward, in press), governs toddlers' social learning and problem-solving attempts (Carpenter, Akhtar, & Tomasello, 1998; Carpenter, Call, & Tomasello, 2002; Meltzoff, 1995) and informs children's understanding of cultural instruments and artifacts (Bloom & Markson, 1998; Defeyter & German, 2003).

The capacity to detect the goal structure of events emerges during infancy. During the first year of life infants encode certain events as goal-directed, that is, they represent human actions (Sommerville & Woodward, 2005; Woodward, 1998; Woodward & Guajardo, 2002; Woodward & Sommerville, 2000; Woodward, Sommerville, & Guajardo, 2001) and certain object motions (Csibra, Biro, Koos, & Gergely, 2003; Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Gergely, Nasady, Csibra, & Biro, 1995) with respect to the objects and outcomes to which they are directed, rather than in terms of their superficial perceptual properties. For instance, after watching an actor reach for and grasp a toy, infants show a stronger novelty response to a change in the actor's goal than a change in the spatial location or trajectory of her reach (Woodward, 1998). This basic ability to construe action with respect to external goals may form the cornerstone for an understanding of goals as abstract entities that guide human action and govern event sequences (Sommerville & Woodward, 2005). A critical question that emerges from this work concerns the experiences that contribute to infants' ability to view action as goal-centered. In the present study we focused on the role of infants' first-hand experience as agents in supporting their ability to construct goal-centered action representations.

Recent research suggests a candidate system that may contribute to the ability to view action as goal-directed. In non-human primates, neurons in the ventral premotor cortex (mirror neurons) are commonly activated both in the context of the production and observation of goal-directed action (e.g. Rizzolatti & Arbib, 1998; Rizzolatti & Fadiga, 1998), providing a means through which the goals of self and other acts are abstractly represented. A similar system has been documented in humans. Neuroimaging findings indicate an overlap in neural activation during action observation, execution and simulation (Grèzes & Decety, 2001) and behavioral measures indicate that perception and action share a common computational code (Hommel, Muessler, Aschersleben, & Prinz, 2001). Because this coupling between action and perception may emerge early in development (Meltzoff, 2002), it has been suggested that infants' ability to map from self to other (and vice versa) may serve as a catalyst for understanding their own and other's behavior in terms of goals (Meltzoff, 2002; Tomasello, 1999). Moreover, several authors have suggested that such a common coding system may play a foundational role in our understanding of others at an evolutionary level. For instance, it has been suggested that the mirror neuron system observed in non-human primates serves as a precursor to the construction of folk psychology (Gallese & Goldman, 1998) and that the action/perception matching system in mature humans supports intentional attribution via simulation (Blakemore & Decety, 2001).

These considerations, along with speculation regarding the central nature of action experience in cognitive development more broadly (Piaget, 1953), suggest that agentive

experience may contribute to the construction of goal-centered action representations during infancy. Over the first year of life, infants' production of goal-directed acts becomes increasingly frequent, precise and refined. Information gleaned from these experiences may facilitate sensitivity to the goal structure of infants' own and others' actions. This action knowledge may subsequently be extended to allow infants to interpret a broad range of events with respect to goal structure. Such a role for action experience in the construction of goal-centered action representations predicts (a) a correlation between the emergence of goal-directed behaviors and infants' ability to detect goals in the acts of others, and (b) an impact of action experience on action interpretation.

Recent findings from our group provide evidence for the first prediction. During periods of emergence, individual variation in infants' action production correlates with their tendency to interpret observed actions of the same type as goal-directed. One study demonstrated this relation in the context of means-end sequences: 10-month-old infants' ability to pull a cloth to retrieve a toy in a systematic manner was related to their ability to identify the goal of a similar cloth-pulling sequence in the actions of another person (Sommerville & Woodward, 2005). A second study found a similar relation for the production and interpretation of points as object-directed (Woodward & Guajardo, 2002). These findings motivated us to test the second prediction.

We focused on infants' ability to detect the goal structure of a grasping event. Five to 6 months of age marks an emerging level of sophistication in infants' reaching ability, and it is around this same age that infants become sensitive to the goal structure of similar reaching acts performed by other people (Woodward, 1998). Prior to this age infants do not typically perform the smooth and efficient goal-directed reaches of older infants (Bertenthal & Clifton, 1998; Rochat, 1989), nor do they spontaneously encode the goal-directed structure of another persons' reach and grasp.[1] To assess the potential reciprocal relation between action and perception, infants took part in an action task and a visual habituation procedure, and we assessed the impact of action experience on action perception and vice versa.

2. Experiment

2.1. Participants

The participants were 30 healthy full-term 3-month-old infants. Infants ranged in age from 2 months, 29 days to 4 months 1, day. Infants were randomly assigned to either the reach-first condition, performing the action task prior to the habituation procedure (10 males and 5 females; mean age = 3 months, 13 days) or the watch-first condition

[1] Prior to this experiment, we tested 16 3-month-old infants in a similar version of the habituation task featured in this study. This task differed from the present task in only one respect: the actor grasped the toys with a bare hand. Infants in this condition looked equally to new path events ($M = 47.1$, SE = 12.4) and new goal events ($M = 53.9$, SE = 14.9; $t(15)$, $P > .3$) indicating that infants of this age do not spontaneously encode the relation between the actor and her goal object.

receiving the tasks in the reverse order (9 males and 6 females; mean age = 3 months, 10 days).[2]

2.2. Procedures and stimuli

2.2.1. Action task

During the action task, infants sat on their caregiver's lap, supported at the torso, directly in front of a table at chest level. The first 180 seconds of the task consisted of the no mittens phase. A small teddy bear (11 by 9 cm) and a ball (6.75 by 6.75 cm) were placed on the table in front of infants and infants were allowed to interact with these objects unassisted.

After this time had elapsed, we next put a pair of mittens on the infants' hands to which the ball and bear would adhere (mittens phase). These mittens were made of white fabric, with Velcro hook-and-loop fabric covering the palm, and were fashioned after those used by Needham, Barrett, and Peterman (2002). While wearing the mittens, the infants could easily make contact with and pick up the toys (which were covered with the corresponding side of the Velcro hook-and-loop fabric) by swiping or batting at them. Each infant was given 200 s to interact with the toys in this manner. After infants spent several seconds in contact with a given toy, the experimenter removed the toy from the mitten and replaced it in front of the infant to give the infant multiple opportunities to make contact with the toys.

After the completion of the task, a trained coder who was unaware of the condition that infants participated in and individual habituation performance coded infants' (a) object-directed actions, and (b) looks to the toys with and without Velcro mittens using a digital coding program.

2.2.2. Habituation procedure

Infants also took part in a visual habituation procedure, adapted from Woodward (1998) (see Fig. 1). Infants sat in an infant seat or on their parents' lap watching reaching events presented on a puppet stage. A trained observer (who was unaware of the condition that infants participated in and their individual action task performance) recorded their looking duration to the static outcome of each action event (e.g. the actor grasping the toy). Trials lasted 120 s, or until the infant looked away from the event for 2 consecutive seconds. Throughout the task the actor wore a white mitten similar to the one worn by infants in the action task.

During the habituation phase, infants saw an actor reach for and grasp one of two toys (a ball or a teddy bear; larger versions of the toys used in the action task) sitting side-by-side on a stage (see Fig. 1). The actor grasped the toy but did not move it. Once infants' looking time decreased to half of its initial level, we reversed the position of the toys. During the test phase, infants watched two new test events. Infants saw new goal events, which featured a disruption in the relation between the actor and her goal (e.g. the actor grasped a different toy than she had during habituation), and new path events, which

[2] Seventeen additional infants (8 in the reach-first condition and 9 in the watch-first condition) began the experiment but were unable to complete the procedure due to crying.

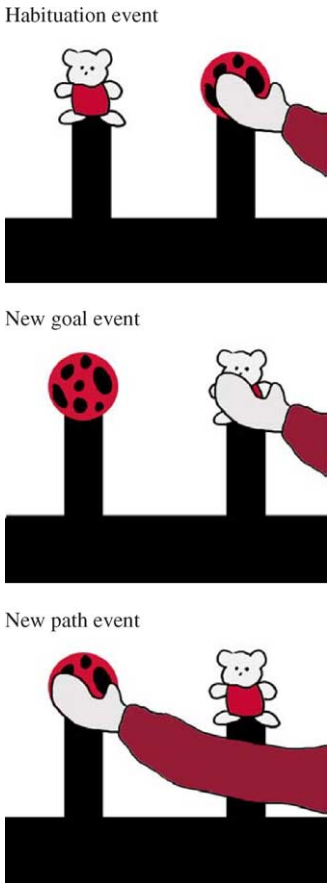

Fig. 1. Habituation task.

featured a disruption in the reach trajectory and location (e.g. the actor reached to a different location for the same toy that she had during habituation). Infants saw 3 test trials of each type, in alteration, for a total of 6 test trials.[3]

2.3. Results and discussion

2.3.1. Habituation procedure

Infants received between 6 and 14 habituation trials, depending on how many trials it took them to reach the habituation criteria. On average infants reached the habituation

[3] Throughout the task, the location of the toys, the side of the habituation reach and the test event shown first were roughly counterbalanced for each condition. During the habituation phase, 8 reach-first and 10 watch-first infants saw the ball on their right-hand side and 8 reach-first and 7 watch-first infants saw the actor reach to the left side of the stage. With respect to test trials, 8 infants in each condition saw the new goal test event first. Preliminary analyses revealed no effect of any of these factors on infants' looking times ($Ps > .1$).

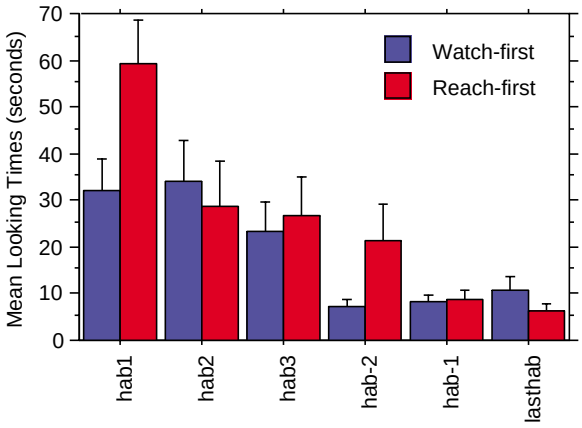

Fig. 2. Looking times on first and last 3 habituation trials.

criteria in 8.0 trials. This number did not differ for reach-first or watch-first infants ($t < 1.0$).

Infants' looking times (in seconds) to the first and last 3 habituation trials are plotted in Fig. 2. Looking declined across habituation trials for both groups ($F(5,140) = 16.8$, $P < .0001$), but looking to the habituation events differed significantly as a function of whether infants received the habituation task first or the reaching task first ($F(5, 140) = 3.1$, $P < .01$). Infants in the reach-first condition looked significantly longer on the first habituation trial than infants in the watch-first condition ($t(28) = 2.4$, $P < .02$). Thus, experience apprehending objects initially increased infants' attention to a similar reaching events performed by another person. Such an effect may reflect infants' ability to recognize correspondences across executed and observed actions and/or an increased motivation to attend to action after acting.

We next examined infants' responses to the test events. Infants looked significantly longer at the new goal event than the new path event (F (1, 28) = 5.06, $P < .03$), and this main effect was qualified by a test trial type by condition interaction ($F(1, 28) = 4.5$, $P < .04$). Infants in the reach-first condition looked significantly longer at the new goal event than the new path event (t (14) = 2.6, $P < .02$), whereas infants in the watch-first condition looked equally to both events ($t < 1.0$; see Fig. 3). This pattern was confirmed at an individual level: whereas 11 of 15 infants in the reach-first condition looked longer to the new goal events than the new path events, only 4 of 15 infants in the watch first condition showed this looking-time preference ($X^2(df = 1) = 6.53$, $P < .03$; Fisher's exact test). These findings indicate that experience apprehending objects directly prior to viewing the visual habituation event enabled infants to detect the goal-directed structure of the event in another persons' actions. Infants in the two groups did not differ in age, trials to reach the habituation criteria, or overall looking time on the test events ($ts < 1.0$) suggesting that none of these factors can account for the reach-first and watch-first groups' differential interpretations of the habituation event.

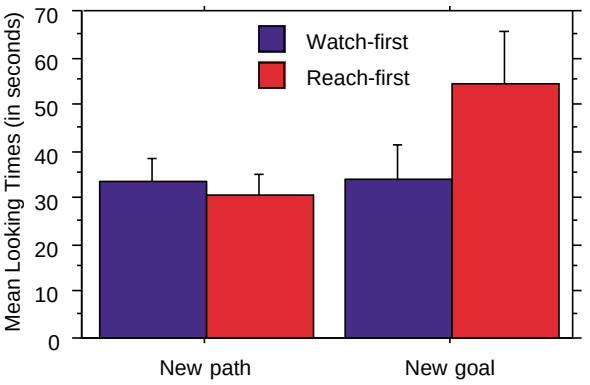

Fig. 3. Looking times to test events (habituation task).

2.3.2. Action task

To more closely investigate the impact of the mittens on infants' object-directed behavior and the relation between habituation task and action task performance, we calculated the proportion of time that infants directed coordinated gaze and manual contact[4] toward the objects (see Fig. 4). Across both conditions, infants spent a greater proportion of time in coordinated gaze and manual contact with the toys when the mittens were on versus when they were off ($F(1,23)=8.6$, $P<.01$), indicating that wearing the mittens enhanced infants' object-directed manual actions. Moreover, while wearing mittens infants' average number of touches to a toy which were directly preceded by a look to the toy ($M=9.5$, SE = 1.03) was significantly higher than the average number of touches in which looks to the toy occurred as a consequence of manual contact ($M=5.9$, SE = .67; $t(26)=3.6$, $P<.001$). This prospectivity of behavior has been suggested to be a hallmark of goal-directed action (von Hofsten, 2004). The order in which infants received the habituation task had no effect on amount of time in coordinated contact with the objects while wearing the mittens ($t<1.0$). Thus, there was no evidence that watching another person reach for and grasp objects influenced infants' tendency to engage in coordinated gaze and manual contact with similar objects in their own actions.

To further investigate the effect of mittened experience on infants' responses in the habituation paradigm, we next focused on infants in the reach-first condition. We conducted a series of correlational analyses to evaluate the relation between infants' habituation responses (as measured by the difference in looking time on the first new goal and new path test trials) and aspects of their experience during the mittens phase. Infants' habituation response was correlated with their overall amount of coordinated gaze and manual contact on the toys while wearing mittens, $r=.57$, $P<.04$, but not with their total amount of visual contact with the toys, $r=.18$, $P>.6$ or their amount of coordinated gaze and manual contact without the mittens, $r=.13$, $P>.7$. Thus, infants' responses to the habituation events seemed to reflect the extent to which they had engaged in organized

[4] Coordinated gaze and manual contact with objects was calculated in seconds and defined as instances of manual contact with the toy(s) that was accompanied by eye gaze toward the toy that was touched.

Fig. 4. Proportion of time in coordinated gaze and manual contact on toys (action task).

mittened actions on the toys rather than perceptual highlighting of the toys or individual differences in motor development.

3. General discussion

The present findings demonstrate that infants rapidly learn from active experience and transfer this knowledge to visually observed events. We suggest that such findings reflect infants' ability to detect the goal structure of action following several minutes of intervention experience engaging in object-directed behavior, and to subsequently apply this knowledge to their perception of the actions of others. Thus, our findings add to the body of literature on rapid learning in young infants (Saffran, Aslin, & Newport, 1996; Marcus, Vijayan, Bandi Rao, & Vishton, 1999; Kuhl, Tsao, & Liue, 2003), provide empirical support for the role of active experience in learning (Piaget, 1953), and add to the growing record documenting relations between agentive experience and other aspects of cognitive development in infancy (Needham et al., 2002; Eppler, 1995; Needham, 1999).

Our findings indicate an impact of reaching production on reaching perception but do not provide strong evidence for the influence of perception on production. It is possible that the direction of this relation is in fact bi-directional, but difficult to measure in young infants. This direction of influence may not have emerged strongly in the current study because the information provided by the habituation events was less rich than that provided by agentive experience. Infants moved the toys after apprehending them, and apprehended the objects via varied reaches, and these features were absent from the habituation events. Both of these factors have been theorized to support infants' goal detection (Kiraly, Jovanovic, Prinz, Aschersleben, & Gergely, 2003).

Our findings indicate that infants' sensitivity to the goal structure of the mittened reach derived from coordinated actions with the mittens, rather than from visual experience with the toys or their initial ability to reach without mittens. Additional research is needed to further specify the aspects of this experience that informed infants' action interpretations,

and to determine whether the effects of such experience are uniquely derived from self-produced actions or whether such effects can also be attained from observational experience. One possibility is that infants learned about the causal effect of the mittens on the toys, and this led them to focus on the relation between the mitten and the toy during the habituation phase, even though this effect was no longer present. This possibility is consistent both with the finding that mature action representations are structured with respect to causal outcomes (Hommel et al., 2001) and with the hypothesis that this is true in infancy (Hauf, Elsner, & Aschersleben, in press; Jovanovic, et al., under review; Kiraly et al., 2003). Action experience may also provide infants with information about the behavioral regularities that typically accompany an actor's goal (e.g. eye gaze, bodily trajectory, bodily orientation; see Baird and Baldwin (2001) and Baldwin, Baird, Saylor, and Clark (2001)). Either of these accounts would predict similar effects of watching an actor use the mittens in a coordinated fashion on infants' subsequent perception of mittened action.

Agentive experience may exert unique effects on action perception. Self-action production may provide increased impetus to attend to action goals. As in older children and adults, increasing motor skill expertise may direct attention to action goals. With skill mastery, attentional resources previously committed to producing sub-components of a motor skill are reallocated to the action goal (Boudreau & Bushnell, 2000; Sommerville & Woodward, 2005). Acting may also provide infants with subjective information that cannot be gleaned from the observed actions of others (Meltzoff, 2002). In particular, self-produced actions may help infants link internal state information with the enactment of external goals. Infants' processing of action events based on self-experience may subsequently be generalized to object motion events when these events share key structural features with action events. Each of these possibilities, though relevant to infants' action knowledge, assumes different levels of knowledge in infants concerning the psychological nature of goals.

These important issues aside, our findings demonstrate that action/perception links extend into infancy (cf. Sommerville & Woodward, 2005) and are in keeping with research indicating a shared representational basis for self and other actions at both a computational and a neural level (Decety & Sommerville, 2003; Grèzes & Decety, 2001; Hommel et al., 2001; Meltzoff & Decety, 2003). In addition, our findings are consistent with the possibility that actions of self and other are represented amodally from early on, allowing infants to readily recognize the correspondence between their own and other's actions (Meltzoff & Moore, 1977). Such an ability to form abstract representations of goal-directed actions would provide infants with a powerful learning mechanism in development by enabling them to rapidly transfer action information across modalities and from one agent to another, and would thereby provide the basis for the acquisition of a host of cognitive abilities that rely on recognizing goal structure in action.

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Institute for Learning and Brain Sciences, Campus Box 357988, Seattle, WA 98195; e-mail: sommej@u.washington.edu.

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