

ABSTRACT

Title of Document: WHAT'S IN A MITTEN?: THE EFFECTS OF ACTIVE VERSUS PASSIVE EXPERIENCE ON ACTION UNDERSTANDING

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Prior research has shown that young infants understand something about others' goals. This understanding has been developmentally linked to infants' own actions. An open question is what aspects of experience are crucial to action understanding. In the current studies, we sought to examine the relation between experience and action understanding in 3-month-old infants and to investigate the differential effects of active and passive experience. Findings from Study 1 demonstrated a threshold effect: a minimal amount of active experience led to subsequent action understanding. In Study 2, we assessed whether visual experience alone would have the same effect by giving another group of infants matched passive experience. These infants, however, did not reap the same benefits from passive experience. These findings demonstrate that active experience provides important information, above and beyond that which can be gleaned from passive experience, at a time when intention understanding is first emerging.

WHAT'S IN A MITTEN?: THE EFFECTS OF ACTIVE VERSUS PASSIVE
EXPERIENCE ON ACTION UNDERSTANDING

By

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Table of Contents

Acknowledgements	ii
Table of Contents	iii
List of Figures	v
Introduction.....	1
Study 1	9
Methods	9
(a) Participants.....	9
(b) Procedure	9
(c) Coding.....	13
Results and Discussion	14
(a) Preliminary Analyses.....	14
(b) Infants' Responses on Test Trials	14
Study 2.....	20
Methods	21
(a) Participants.....	21
(b) Procedure	22
Results and Discussion	24
(a) Comparison of Three Conditions	27
General Discussion.....	28
Footnotes.....	34
References.....	35

List of Tables

Table 1. Median and Mean Looking Times in the Habituation Paradigm

List of Figures

Figure 1. Habituation Paradigm

Figure 2. Relation Active Experience and Looking Times

Figure 3. Relation Between Passive Experience and Looking Times

Introduction

An understanding of the intentions of others is an essential aspect of what makes humans a unique species. As social beings, an understanding of others' goal-directed actions is essential to our social, cognitive, and language development. For example, in early word-learning, infants must be able to form associations between seemingly arbitrary sounds and objects or actions around them. Without the ability to understand the intention of another individual in referring to a particular object during a labeling instance, learning language would be impossible. An understanding of others' intentions guides infants' learning not only in word-learning, but also in social referencing and imitation (Baldwin & Moses, 1996; Meltzoff, 1995; Tomasello, 1999). Deficits in understanding others are devastating to both social life and social learning, as can be seen in the case of autism (Baron-Cohen, 1995).

A burgeoning literature spanning several laboratories and paradigms provide converging evidence that typically developing infants possess this critical understanding of others' actions as goal-directed within the first year of life (see Woodward, 2005 for summary). Initial evidence for this understanding comes from experiments using visual habituation paradigms. In this now classic paradigm, infants are habituated to (repeatedly shown) events involving an agent acting on an object. Within the first 12 months, infants demonstrate novelty preferences for changes in goal-relations but not changes in physical-relations, suggesting that they view the goal-directed nature of the interaction between agent and object as more salient than the physical aspects of the event (Gergely, Nadasdy, Csibra, & Biro, 1995; Woodward, 1998, 1999). Subsequent findings using different outcome measures (e.g.,

eye-tracking, imitation, and other overt responses) provide further evidence that infants view others' actions as structured by goals within the first year (Behne, Carpenter, Call, & Tomasello, 2005; Falck-Ytter, Gredeback, & von Hofsten, 2006; Hamlin, Hallinan, & Woodward, in press; Luo & Baillargeon, 2007).

The fact that this crucial understanding is present early in life makes the assumption that it is strongly driven by innate capacities an intriguing possibility. Indeed, several current accounts stress the contributions of innate structures in action understanding (e.g., Biro & Leslie, 2006; Gergely & Csibra, 2003; Kiraly, Jovanovic, Prinz, Aschersleben, & Gergely, 2003). It is also possible, however, that this early and essential understanding may be influenced by components of experience that are universal and present early in life. In fact, dependence on reliably present experiences for typically developing abilities is a common developmental mechanism across many species (Greenough, Black, & Wallace, 1987). One way important experiences can be dependably present is if the developing organism produces the experiences itself. A classic example of the necessity of self-produced actions for understanding others is evidenced in research by Gottlieb (1975, 1991) demonstrating that ducklings require the experience of producing a peep in order to perceive maternal calls (devocalized ducklings did not respond specifically to their mother's call). Examples like this raise the question of whether early self-produced experiences help shape infants' perception of goal-directed actions.

The notion that first-person agentic experience plays an important role in action understanding has been in place for over a century (Baldwin, 1897; Piaget, 1953) and is supported by several current theories (Barresi & Moore, 1996; Meltzoff,

2005; Tomasello, 1999; Woodward, 2005). Recent findings of mirror neurons in monkeys and mirror systems in humans indicating a direct neural link between action production and action understanding have led to renewed interest in this relationship and its importance in development (Decety & Sommerville, 2003; Gangitano, Mottaghy, & Pascual-Leone, 2001; Gerson & Woodward, in press; Grezes & Decety, 2001; Rizzolatti & Arbib, 1998; Rizzolatti & Fadiga, 1998). Although several perspectives note the important contributions of first-person experience, the specific mechanisms by which self-produced actions play a role in action understanding are currently unknown.

On a basic level, producing actions oneself allows an individual to view the outcomes of these events and the statistical regularities that occur when particular actions are produced. In fact, past research has shown that infants under two years of age attend uniquely to the effects of actions and are able to extract statistical regularities relating to goals in events (Baldwin, Baird, Saylor, & Clark, 2001; Kiraly et al., 2003; Saffran, Aslin, & Newport, 1996). In this way, self-produced action is a salient way for an individual to learn about actions in the same way he or she may learn through observational experience.

Beyond this, however, it is possible that first-person agentic experience provides unique information that is not attainable from passive observation. An individual must have a representation of his or her goal in order to successfully complete an intentional action that is part of a sequence of events. Thus, experiencing this representation oneself may aid in understanding the intentional actions of others.

Consistent with this view, recent evidence indicates that infants' own action abilities are related to their perception of others' actions. The first evidence for this was circumstantial. Researchers found that infants' responses to others' actions as goal-directed emerged at around the time these actions emerged in infants themselves (Woodward, Sommerville, & Guajardo, 2001). For example, around four or five months of age, infants begin to produce well-structured goal-directed reaches themselves (Bertenthal & Clifton, 1998; Rochat, 1989) and also begin to understand reaches as intentional in others (Woodward, 1998). Following on these observations, researchers then looked for more direct evidence for linkages between infants' action production and action understanding.

One way this link has been examined in more detail is through correlational studies. In correlational studies, researchers investigate phenomena at an age when a great deal of individual variation exists in the capacity to both produce and understand a particular action so that the links between these abilities can be explored while accounting for the many confounding factors that likely co-occur with general development. For example, between 10 and 12 months of age, a great deal of individual variation exists in infants' ability to both produce and understand means-end actions, such as pulling a cloth to get a toy. Sommerville and Woodward (2005) compared the individual differences in infants' understanding of the goal structure of a cloth-pulling sequence and their ability to produce a well-organized cloth-pulling action to attain a toy. They found a correlation such that infants who were better able to produce planful cloth-pulling actions understood the end-goal of another's cloth-pulling action as the toy at the end of the cloth in a habituation paradigm, whereas

those infants who were unable to produce planful actions understood the experimenter's goal as the cloth (thus, they understood a simpler goal sequence in this event). Additional correlations have been found between infants' ability to produce and understand pointing (Brune & Woodward, 2007; Woodward & Guajardo, 2002).

This evidence supports the notion that the production and understanding of particular actions likely exert an influence on one another in development. In order to more closely investigate this possibility and determine the causal direction of this link, Sommerville and colleagues (Sommerville, Woodward, & Needham, 2005) conducted an intervention study with three-month-old infants who are not proficient with their reaches and also do not understand the goal-directed nature of another's reach. In this study, three-month-olds were fitted with Velcro mittens that enable infants of this age to apprehend objects and become more planful with their reaching actions (Needham, Barrett, & Peterman, 2002). The key question was whether this engagement in object-directed activity would change infants' perception of others' actions. This study used a habituation paradigm, adapted from Woodward (1998), in order to assess infants' action understanding. Infants were habituated to a mittened hand reaching for one of two toys on a stage. After habituation, the placement of the two toys was switched and infants saw alternating trials in which the hand either reached for the same toy in a new place (old-goal trials) or a new toy in the same place (new-goal trials). Longer looking to new-goal trials indicated that infants interpreted the change in relation between the hand and the object as more novel than the change in physical motion. Infants with experience manipulating toys using Velcro mittens looked longer to new-goal trials than old-goal trials, indicating that

they understood the relation between the experimenter and the object of her reach. This pattern of responses in the habituation paradigm is similar to that of older infants who have been shown to understand this relationship (Woodward 1998, 1999). Infants who did not have experience with mittens prior to habituation, however, did not show this same pattern - they did not differentiate between test trials in the habituation paradigm, consistent with previous findings with infants of this age (Sommerville et al., 2005).

In addition, the training with Velcro mittens, and not their experience outside of the laboratory, led the infants to understand the actor's goal in habituation. This was indicated by a correlation between object-directed activity with mittens and looking times in habituation, such that infants who were more active with the mittens looked relatively longer at the new-goal trials. No such correlation between barehanded activity (assessing abilities before training) and habituation times was found.

This study (Sommerville et al., 2005) provided the first evidence that first-person experience affects perception of others' actions. One limitation of this study, however, is that it did not differentiate between what the infants gained from observation of their actions and what was truly unique to their *active* experience. Considering this, some researchers have argued that the knowledge gained from this experience could have been due to infants' observation of their actions, rather than having been unique to active experience (Biro & Leslie, 2006).

In order to determine whether the self-produced nature of these actions was critical, first-person experience needs to be compared to passive, observational

experience. A recent study by Sommerville, Hildebrand and Crane (in press) differentiated between these two possibilities in older infants. This study built upon the correlational evidence linking the production and understanding of means-ends actions in the Sommerville and Woodward (2005) study. One group of 10-month-old infants was trained to use a cane to reach for a toy. A second group of infants (of the same age) passively observed an experimenter training another individual to produce this action. In this condition, infants saw a set number of trials equal to the average number of trials experienced by infants in the active condition. After this training session, infants participated in a habituation paradigm in order to assess their understanding of the ultimate goal of the sequence. Infants trained to use a cane to pull a toy showed evidence of representing the ultimate goal of the cane-pulling sequence in the habituation paradigm, whereas infants who simply observed the cane-pulling training session did not. Additionally, there was a correlation between infants' ability to produce the action in training (their active experience) and their looking times during habituation, such that those infants better able to produce the cane-pulling action looked relatively longer at the new-toy trials in the habituation paradigm. Whether any similar relation between amount of passive experience and action understanding was present could not be assessed since all infants in the observation condition received roughly the same amount of experience.

This study by Sommerville and colleagues (in press) demonstrated that active experience uniquely influenced 10-month-old infants' understanding of the intentions behind a means-end action. This does not address, however, whether the same is true of younger infants. In the current studies, we are particularly interested in the

importance of self-produced experience at a time when both motor and conceptual abilities are extremely limited. It is currently unknown whether self-produced experiences become important once basic skills are already in place or if they are essential from the onset. This is the question that motivates the current studies.

In order to examine the origins of intention understanding, we first sought to replicate the Sommerville, Woodward, and Needham (2005) study and gain more information about the nature of the relationship between active experience and action understanding. By doing so, we investigate the robustness of this effect and gain further insight into the mechanisms driving this relationship. In Study 1, two groups of three-month-old infants participated in both a training session and a habituation paradigm. Infants in the *active condition* were given experience producing object-directed actions with Velcro mittens during a training session, thus providing a direct replication of the study by Sommerville and colleagues (2005) study. Infants in the *control condition* were given the opportunity to interact with toys using their bare hands but received no training with mittens. This study offers a direct investigation of the relation between active experience and infants' subsequent responses.

In order to clarify whether first person experience is necessary for the effects on infants' action perception, however, a critical test was to provide closely matched observational experience. Thus, in Study 2, we test whether effects of experience were uniquely derived from first-person experience or from the observation of these actions. To this end, the findings from Study 1 were used as a model for the matched passive experience in Study 2. That is, we used a yoked observation paradigm in which the self-produced activity of infants in Study 1 was used to create scripts for

the observational experience received by infants in Study 2. We then compared across these studies in order to better understand how these different kinds of experiences differentially influence action understanding.

Study 1

Methods

(a) Participants

A total of 48 full-term three-month-old infants participated in Study 1. Infants ranged in age from three months to four months (mean age = 3 months, 14 days). Twenty-four infants were female. The infants were all full term (at least 37 weeks gestational age) and recruited from the Washington, DC metro area using a database created through mailings and advertisements. The sample of infants was 8% Hispanic, 2% Asian, 17% African-American, 46% Caucasian, and 27% multiracial or unreported. Twenty-four infants took part in each of the conditions (active and control).

All infants who completed at least one pair of test trials were included in final analyses. An additional 34 infants began the procedure but were not included in the dataset because of crying or failure to complete at least one pair of test trials in the habituation paradigm ($n = 21$), procedure error ($n = 10$), or failure to produce any actions with mittens ($n = 3$).

(b) Procedure

The study consisted of two phases. Infants in each of the conditions always participated in a training phase before the habituation paradigm. The nature of the

training differed for infants in the two conditions; however, the habituation paradigm was identical for both conditions.

(i) Training Phase

During the training phase (i.e., action task), infants sat on a parent's lap. A small white table was at their torso level and parents were asked to support their children around the torso so that the infants could easily reach their hands in front of them and onto the table. A camera sat directly in front of the table and level with the infant.

Barehanded pre-exposure. To start, infants in both conditions were introduced to the experimental toys on the tabletop and given the opportunity to act on them with their bare hands. This barehanded pre-exposure provided a measure of infants' reaching skill without the mittens. The experimenter (E1) placed a small bear (five inches in length) and a small ball (two inches in diameter), both covered in Velcro, a few inches apart from one another in the center of the table, within arm's reach of the infant. During the three-minute session, the experimenter ensured that the infant's hands were on top of the table and drew the infant's attention to the toys by tapping on the table or moving the toys periodically. Following this pre-exposure, the training phase ended for infants in the control condition; infants in the active condition then received mittened training.

Active mittens training. In this session, the experimenter fitted the infant with Velcro mittens after the barehanded session. The experimenter ensured that the infant's hands were on top of the table and drew the infant's attention to the toys if he or she was not paying attention. When the infant apprehended a toy, the experimenter

allowed the infant to hold it until he or she lost eye contact with the toy. The experimenter then detached the toy from the infant's mitten and drew his or her attention back to the toys. This session lasted between three and five minutes.

(ii) Habituation Phase

Immediately following the training phase, all infants were tested in a habituation procedure modeled after that used by Sommerville and colleagues (2005) and designed to assess infants' encoding of reaching actions as goal-directed. This task took place in a different room, equipped with a testing booth and cameras to record the event and the view of the infant. During this task, infants sat on a parent's lap and faced a stage holding a bigger version of the ball and bear from the action task. Parents were asked not to talk or point when the curtain was lowered so as not to influence their infant's looking in any way. Further, they were asked to look at their infant, rather than the event, during the test trials in order to prevent any subconscious influencing.

The camera view of the infant was sent to an online coder who sat in another room. The coder was unaware of the order of events and was thus unbiased. She was trained to judge whether the baby was looking at the event during each of the trials. All trials were infant-controlled. Trials ended when infants looked away for two consecutive seconds or looked for a maximum of 120 seconds.

During habituation trials, the presenter, who sat to the side of the stage out of the child's view, reached out her hand, wearing a large Velcro mitten, and placed her hand in front of one of the two toys, as if grasping it (see Figure 1). Once the presenter's arm reached the toy, she held her hand steady until the trial was over and

the curtain was raised. Habituation trials were repeated until the infant was habituated (when the length of the last three trials was less than half of the length of the first three trials) or for 14 trials.

After habituation, the presenter switched the placement of the two toys on the stage while the curtain was raised. One familiarization trial occurred in which the infant saw the new placement of the toys without any action. Infants were then shown six test events that alternated between new-goal and old-goal events. In the new-goal event, the presenter reached for a new toy (the toy that was then in the same position as the toy she had reached for in habituation). In the old-goal event, she reached for the same toy as in habituation (this toy was then in a new place on the stage). In both of these events, the presenter held her arm in position until the end of the trial. The toy grasped in habituation, whether the habituation reach was for the far or near toy, and the order of test trials was counterbalanced across infants. These factors were yoked for infants of similar age and gender across conditions so that each infant in the active condition had a matched pair in the control condition.

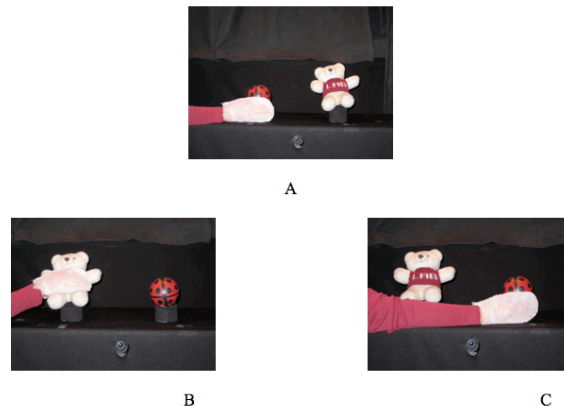


Figure 1. Infants were habituated to a mittened hand reaching for one of the two toys on the stage (A). In test trials, infants saw the hand reach for a new toy in the same place (new-goal trials; B) or the same toy in a new place (old-goal trials; C).

(c) Coding

(i) Action Task

A trained coder used a digital coding program (Mangold, 1998) to code the training session for the amount of time the infant spent looking at and touching each of the objects. In order to obtain a measure indicating the extent to which infants engaged in object-directed activity, the amount of time each infant spent simultaneously looking at and touching the same object (s) was extracted for both the barehanded and mittened activity. This measure of visual attention in coordination with manual contact as an indication of object-directed activity is both theoretically compelling and in following the procedure used by Sommerville et al. (2005). Twenty-five percent of the sessions were randomly chosen for reliability coding. The time spent in object-directed activity according to the two coders was correlated, ($r = .98$, $P < .001$).

(ii) Habituation Paradigm

Infants' looking times to the habituation, familiarization, and test events were coded on-line using a coding program (Casstevens, 2007; Pinto, 1994). A second trained coder reliability coded all of the sessions. The length of test trials according to the two coders was correlated ($r = .96$, $p < .001$).¹. As a more stringent test, the proportion of test trials in which the online and reliability coders were in agreement as to the infant's look away that ended the trial was recorded. Coders agreed on the end of the test trials 88% of the time in the active condition and 76% of the time in the control condition. This analysis allowed us to consider whether the direction of the disagreements was biased. Disagreements were randomly distributed with respect

to the hypothesis (longer looking to new-goal than old-goal test trials), (Fisher's exact test, *ns*).

Results and Discussion

(a) Preliminary Analyses

Infants in the active and control conditions reached habituation in an average of 9.4 and 9.6 trials, respectively. Due to positive skew in the data, all looking times were log transformed before being entered into analyses. A repeated measures analysis of variance with the habituation trials (first three and last three habituation trials) as the within subjects factor and condition as the between subjects factor indicated that infants' looking times declined across habituation trials for both groups ($F(5, 42) = 9.23, p < .001$) and decrease in looking time did not differ as a function of condition ($F(5, 42) = 1.66, ns$). Thus, infants in the two conditions demonstrated similar levels of attention prior to test trials.

In addition, a paired samples t-test revealed no difference in barehanded activity between infants in the two conditions ($t(23) = .13, p = ns$). This indicates that infants in the two conditions were comparable in ability to produce object-directed actions prior to any training with mittens. It also verifies that any differential effects found between groups were not due solely to barehanded experience in the laboratory prior to the habituation paradigm.

(b) Infants' Responses on Test Trials

The focal question of this study was whether responses in test trials (and thus, action understanding) would differ as a function of infants' condition. Preliminary

analyses revealed that differences in infants' responses to the two types of test trials did not vary significantly over trial pairs. Therefore, infants' average looking times to new-goal and old-goal trials were used as the dependent variable in the main analyses. The nature of our design allowed us to account for all counterbalanced factors (i.e., age, sex, near or far reach in habituation, goal toy in habituation, and first test trial) with the yoking variable. A repeated measures analysis of variance with test-trial type (old-goal or new-goal) as the within subjects factor and condition (active or control) and yoking as the between subjects factors revealed a marginal interaction between test-trial type and condition ($F(1, 23) = 2.83, p = .11$), suggesting that infants in the two conditions responded differently to test events in the habituation paradigm. This analysis did not reveal a main effect of test-trial type or an interaction between test-trial type and yoking.

Our main hypotheses concerned the effects of experience within the active condition. Therefore, we next consider the relationship between active experience and action understanding more closely.

(i) Active Condition

Preliminary analyses revealed no interactions between test-trial type and age, sex, goal toy in habituation, or first test trial. Therefore, subsequent analyses were collapsed across these factors.

In order to examine the effects of experience, a repeated measures analysis of variance with test trial type (old-goal or new-goal) as the within subjects factor and a median split of active experience (above or below median amount of active experience) and habituation reach (near or far) as the between subjects factors

revealed no significant main effect of test trial type ($F(1, 20) = 2.49, p = .13$; see Table 1 for looking times), but revealed an interaction between test trial type and active experience ($F(1,20) = 7.62, p < .02$). Follow-up paired samples t-tests revealed that infants with below-median experience did not differentiate between new and old-goal test trials ($t(11) = .67, p = ns$; median looking times to old-goal and new-goal test trials were 9.79s and 10.34s, respectively), whereas infants with above-median experience looked significantly longer to new-goal test trials than old-goal test trials ($t(11) = 2.53, p < .03$; median looking times to old-goal and new-goal test trials were 3.20s and 7.62s, respectively). In addition, there was a type by habituation reach interaction ($F(1,20) = 7.62, p < .02$). Inspection of the means indicated that infants tended to look longer to test events when they saw a far reach than a near reach.

Table 1. *Median and Mean Looking Times in the Habituation Paradigm*

	<i>Average Old-Goal Trials</i>	<i>Average New-Goal Trials</i>		<i>Average Old-Goal Trials</i>	<i>Average New-Goal Trials</i>
<u>Active (N = 24)</u>			<u>Active (N = 20)</u>		
<i>Median</i>	7.09	9.16	<i>Median</i>	4.98	9.16*
<i>Mean</i>	13.12	13.45	<i>Mean</i>	9.20	12.70
<i>Standard Error</i>	3.36	2.86	<i>Standard Error</i>	2.74	3.07
<u>Observation (N = 24)</u>			<u>Observation (N = 20)</u>		
<i>Median</i>	5.41	6.56	<i>Median</i>	5.41	6.56
<i>Mean</i>	8.93	9.79	<i>Mean</i>	8.25	10.08
<i>Standard Error</i>	1.81	2.00	<i>Standard Error</i>	1.67	2.34
<u>Control (N = 24)</u>			<u>Control (N = 20)</u>		
<i>Median</i>	6.07	5.70	<i>Median</i>	8.41	6.49
<i>Mean</i>	9.59	7.31	<i>Mean</i>	11.11	8.15
<i>Standard Error</i>	1.95	1.33	<i>Standard Error</i>	2.19	1.53

* $p < .03$.

In order to explore the relation between active experience and action understanding in more detail, we next conducted regression analyses. We first created a single score indicating infants' relative preference for new-goal test trials compared to old-goal trials: (average looking time to new-goal test events)/(average looking time to new-goal test events + average looking time to old-goal test events). This score isolates the extent to which infants preferred the new-goal test trials independent of individual differences in base rates of looking.²

A Spearman rank correlation revealed a correlation between relative preference for new-goal test trials and amount of active experience, $r = .42, p < .05$. These findings replicate the relation between active experience and action understanding found in Sommerville et al. (2005) and demonstrate that training with Velcro mittens led to an increased sensitivity to the goal-directed nature of another's reach. There was no correlation between their looking times and their barehanded experience ($r = -.03, p = ns$), indicating that ability to produce object-directed reaches prior to training (as measured by barehanded experience) did not influence infants' looking to test trials.

Inspection of the scatterplot (see Figure 2) suggested that the relation between experience and action understanding is not best explained by a linear relationship. Curve fitting regression analyses revealed that the relationship between the relative preference for new-goal trials and active experience was better accounted for by a logarithmic function ($R^2 = .25, p < .02$) than by a linear function ($R^2 = .16, p = .05$). This analysis suggests that a threshold level of experience is necessary, and after this

threshold is met, relative differences in experience are less important to responses in the habituation paradigm.

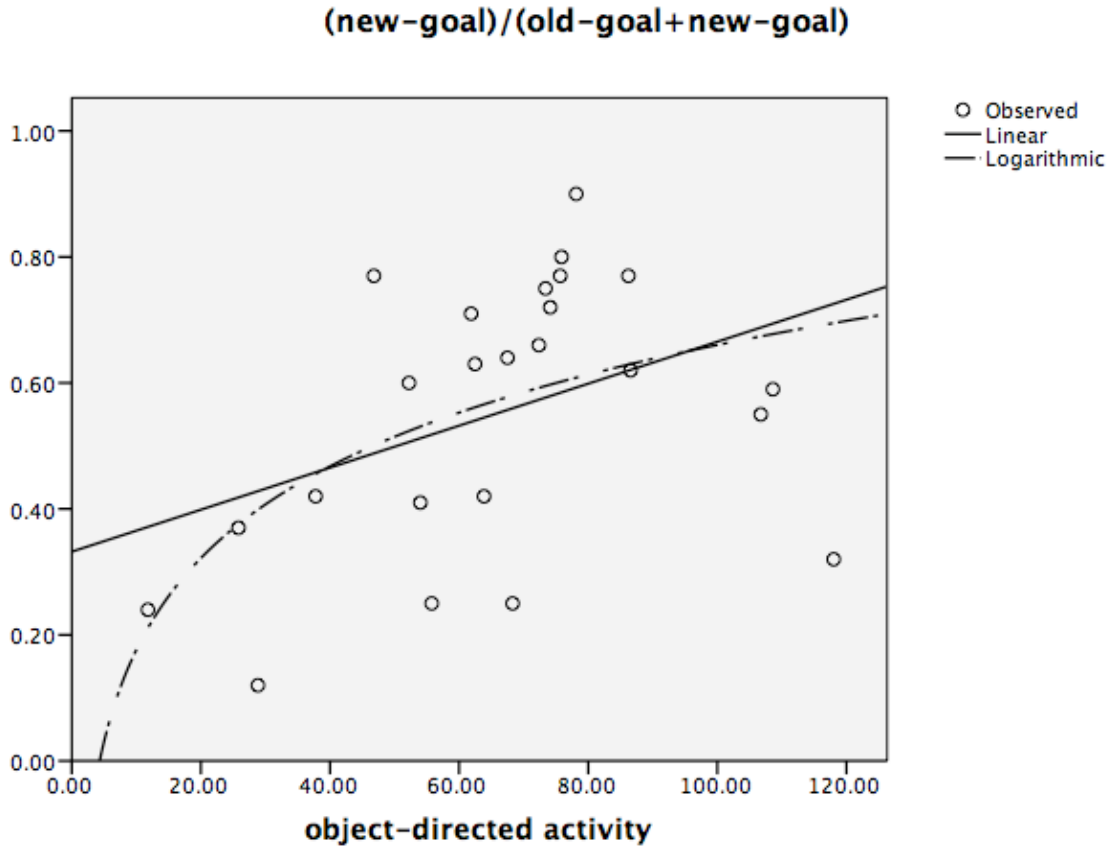


Figure 2. Relation Active Experience and Looking Times.

Due to the logarithmic relationship between infants' active experience and their preference for new-goal test trials and the fact that we were interested in those infants who received sufficient experience, we also separately examined those infants whose active experience was in the upper 75th percentile. This distinction corresponded with a cutoff such that infants in the top 75th percentile produced over 45 seconds of object-directed activity, whereas those in the lower 25th percentile produced less than 40 seconds of object-directed activity. In this group of 20 infants,

a paired samples t-test revealed a significant difference between looking to old- and new-goal test trials ($t(19) = 2.53, p < .03$) such that infants looked longer to new-goal than old-goal trials (see Table 1 for looking times). Within this group of 20 infants, 15 infants looked longer at the new-goal test trials ($p < .05$ by sign test).

(ii) Control Condition

Preliminary analyses revealed no interactions between test-trial type and any counterbalancing factors. Therefore, remaining analyses were collapsed across all counterbalancing factors. A paired samples t-test revealed no significant differences between looking times to old- and new-goal test trials ($t(23) = 1.01, ns$). Therefore, looking during test trials did not seem to be strongly influenced by test-trial type or any other factors in this condition.

A Spearman's rank order correlation revealed no relationship between infants' barehanded activity and their relative preference for new-goal test trials ($r = -.034, p = ns$). This indicates that looking during test trials was not influenced by infants' ability to perform object-directed reaches prior to their experiences at the laboratory. It also demonstrates that their experience producing barehanded actions in the laboratory did not influence their looking to test trials in the habituation paradigm.

As a further analysis, we selected those 20 infants in the control condition who were yoked (and were thus matched for experience in the habituation paradigm, as well as age and gender) to those infants in the active condition who produced the upper 75th percentile of active experience. In the 20 matched control infants, there was no preference for either old- or new-goal test trials ($t(19) = 1.56, ns$). Seven of the 20 infants looked longer at new-goal test trials (ns by sign test).

In order to assess whether there was an interaction between condition and looking times to test trials in this group of matched infants, we conducted a repeated measures analysis of variance with test trial type (old-goal or new-goal) as the within subjects factor and condition (active or control) as the between subjects factor. This revealed a type by condition interaction ($F(1,38) = 8.35, p < .01$). In sum, infants in the active condition who received sufficient experience demonstrated a reliable preference for new-goal test trials, whereas matched infants in the control condition showed no such preference.

In summary, Study 1 demonstrated that infants who received sufficient training producing object-directed activity with Velcro mittens showed a selective novelty response to goal change events, and thus understood another's reach as goal-directed. In accord with previous research, the amount of active experience influenced infants' looking to test events. Further, this study shed light on the nature of the logarithmic, rather than linear, relation between these two factors, suggesting that a minimal amount of experience is necessary for conceptual change, after which relative amounts of experience are not particularly influential. This study also provides a foundation for answering the vital question of the effects of observation, which we examine in Study 2.

Study 2

Study 2 was designed to address several remaining questions concerning the influence of experience on infants' intention understanding. This study aimed to determine whether infants who receive passive experience with mittens would differentially respond to old- and new-goal test trials in the habituation paradigm. It

was designed so that infants' amount of passive experience was yoked to the active experience of infants in the active condition from Study 1. This design allowed us to examine whether there was a similar relationship between passive experience and action understanding.

Findings from this study contribute to the examination of the origins of intention understanding in unique ways. They directly inform our understanding of the relative contributions of innate factors and experience. According to one perspective, the understanding infants gained from experience in Sommerville and colleagues' (2005) study could have been a function of the perceptual cues inherent in infants' actions while wearing the Velcro mittens (Biro & Leslie, 2006). If this were true, we would expect passive experience to produce the same effects (demonstration of action understanding in the habituation paradigm) as active experience. In contrast, if only the infants in the active condition, and not those in the observation condition, understand the goal of an actor's grasp in habituation, this would support theories proposing that active experience is vital to action understanding at the onset.

Methods

(a) Participants

Twenty-four three-month-old infants were included in our final data set. Infants ranged in age from three months, one day to four months, zero days (mean age = 3 months, 14 days). Twelve infants were female. As in Study 1, the infants were all full term (at least 37 weeks gestational age) and from the Washington, DC metro area and recruited from the same database. The sample of infants was 8%

Hispanic, 8% Asian, 25% African-American, 38% Caucasian, and 21% multiracial or unreported.

All infants who completed at least one pair of test trials were included in final analyses. An additional 16 infants began the procedure but were not included in the dataset because of crying or failure to complete at least one pair of test trials in the habituation paradigm (n = 13) or procedure error (n = 3).

(b) Procedure

This study consisted of two tasks. Infants always participated in the observation training before the habituation paradigm. All aspects of the procedure were identical to Study 1, except for the training phase that followed barehanded pre-exposure.

(i) Observation Mittens Training

Following the barehanded pre-exposure session, infants participated in an observation training session. The goal of the observation training session was to match active experience of infants in the active condition in Study 1 as closely as possible to the passive experience (measured as the time spent watching an experimenter engage in object-directed activity) of infants in the observation condition in this study. In order to achieve this goal, infants in the observation condition were yoked to infants in the active training condition of similar age and gender, in order to control for any confounding factors of age or gender. The amount of time each infant spent in object-directed activity (as coded in Study 1) was rounded up by approximately five seconds in order to create a script that ensured that the matched infant in the observation condition received this amount of exposure at a

minimum. We recognize that exact matching is difficult, so we erred on the side of giving infants in the observation condition more experience.

During the training session, E1 wore a large Velcro mitten and placed the toys just out of reach of the infant. A second experimenter (E2) stood in a neighboring room and told E1 which toy to touch with the mitten first according to the script. The order in which the experimenter touched each of the objects was randomized. While E1 moved the toy around on the table with the mitten, a third experimenter (E3) watched the infant through a two-way mirror and told E2 when the infant was gazing at the toy that E1 was touching with the mitten. E2 used a stopwatch to measure the length of time the infant spent looking at the toy E1 was moving with the mitten. She told E1 when to touch which object based upon the predetermined script. Throughout this session, E1 used her unmittened hand to tap on the table in order to draw the infant's attention to the action when he or she was distracted.

Observation sessions were coded for the amount of time the infant spent watching the toys and the amount of time the experimenter spent touching each of the toys. The time infants spent watching the toy the experimenter was touching was then extracted in order to ensure that the script was accurately followed and to generate an estimate, for each infant, of the amount of visual experience they actually received. Twenty-five percent of these sessions were reliability coded and the time spent viewing object-directed activity according to the two coders was correlated, ($r = .9$, $p < .001$). As mentioned above, we erred on the side of giving infants in the observation condition more experience than infants in the active condition (Mean times observing mittened actions = 81.91s [$SE = 5.06$] and 66.38s [$SE = 5.23$],

respectively). Infants' passive experience in this study was correlated with infants' active experience in Study 1 ($r = .90, p < .001$), demonstrating that the infants' experience was successfully yoked.

(ii) Habituation Paradigm

Immediately following the training phase, infants in this experiment participated in the exact same habituation paradigm as infants in Study 1. Infants in the observation condition viewed an identical configuration of the habituation paradigm as their yoked partner (i.e., same placement of toys, direction of reach, and first test trial). Coding of all sessions was done both online and by a reliability coder. The length of test trials according to the two coders was correlated ($r = .90, p < .001$).¹ As a more stringent test, the proportion of trials on which the two coders agreed on the end of the trial was 79%. In addition, the direction of the disagreements was analyzed in order to assess for any possible bias in the coding. Disagreements were randomly distributed with respect to the hypothesis (longer looking to new-goal than old-goal test trials; Fisher's exact test, *ns*).

Results and Discussion

Infants reached habituation in an average of 9.25 trials. A repeated measures analysis of variance with habituation trials (the first three and last three habituation trials) as the within subjects factor indicated that infants' looking times declined across habituation trials ($F(5,19) = 8.37, p < .001$).

As in Study 1, the dependent variable was the average looking time to old- and new-goal test-trials. Preliminary analyses revealed no significant interactions

between counterbalanced factors and test-trial type. Therefore, remaining analyses were collapsed across these factors.

In order to examine the effects of passive experience, a repeated measures analysis of variance with test-trial type (old-goal or new-goal) as the within subjects factor and a median split of passive experience (above or below median amount of passive experience) as the between subjects factor revealed no main effect of test-trial type (old-goal or new-goal), ($F(1,22) = .03, ns$; see Table 1 for looking times), and no interaction between test-trial type and passive experience ($F(1,22) = .09, ns$).

To further test whether there was any relation between passive experience and action understanding, we created a single proportion score indicating infants' measure of relative preference for new-goal test trials. A Spearman's rank correlation revealed no significant correlation between relative preference for new-goal test trials and infants' passive experience ($r = .08, ns$). Follow up curve fitting analyses demonstrated that neither a linear function ($R^2 = .02, ns$) nor a logarithmic function ($R^2 = .02, ns$) indicated any relationship between passive experience and action understanding (see Figure 3). There was also no correlation between their looking times and their barehanded experience ($r = .01, ns$).

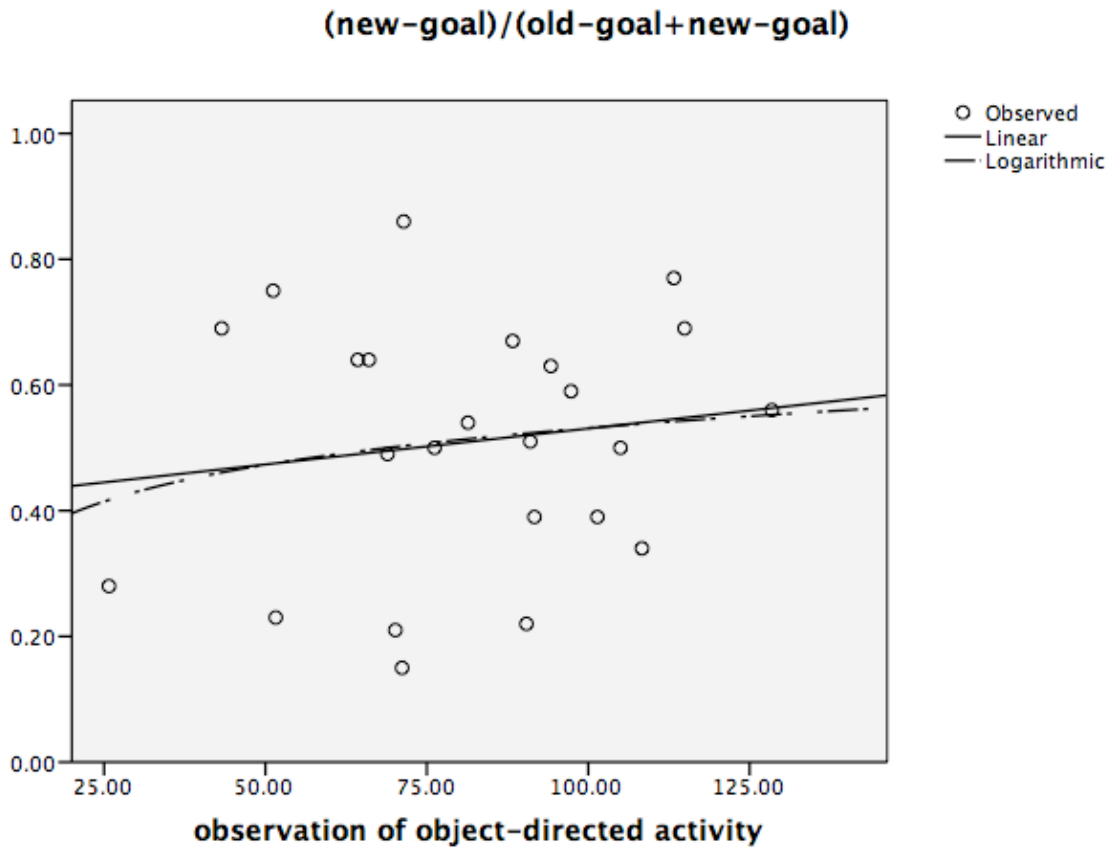


Figure 3. Relation Between Passive Experience and Looking Times.

We also separately examined those infants who were yoked to the 20 infants in the active condition from Study 1 with the highest amount of active experience. Due to the design of the study, these were also the infants with the upper 75th percentile of passive experience. In this group of 20 infants, a paired samples t-test revealed no significant difference between looking times to old- and new-goal test-trials ($t(19) = .28, ns$). Only those infants whose average looking times to old- and new-goal test-trials differed by more than a second were analyzed in a sign test (due to the fact that less than one second difference in average looking was likely due to chance).³ Ten of 17 infants looked longer to new-goal test trials (*ns*).

(a) Comparison of Three Conditions

Based on the findings from Study 1, final analyses compared infants with the top 75th percentile of active experience, infants with the top 75th percentile of passive experience, and the 20 matched infants in the control condition. In order to ensure that the infants in each of these conditions did not differ from one another in their attention to events during habituation or in their ability to produce object-directed actions prior to training, we conducted some preliminary analyses. A repeated measures analysis of variance with the habituation trials (first three and last three habituation trials) as the within subjects factor and condition (active, observation, or control) as the between subjects factor indicated that infants' looking times declined across habituation trials for all groups ($F(5,53) = 13.35, p < .001$) and decrease in looking time did not differ as a function of condition ($F(10,108) = .89, ns$), indicating no difference in attention prior to test events across conditions. A one-way analysis of variance with barehanded activity as the dependent variable and condition as the factor revealed no difference between the three groups in their barehanded activity ($F(2,57) = .95, ns$).

A univariate analysis of variance with relative preference for new-goal test-trials (as indicated by the proportion score noted above) as the dependent variable and condition as a fixed factor revealed a significant effect of condition, $F(2,57) = 4.53, p < .02$ (see Table 1 for looking times). Planned comparisons were conducted to follow up on these interactions. Paired sampled t-tests based on the matching of infants across conditions revealed that the active and control conditions differed significantly from one another ($t(19) = 4.32, p < .001$), as mentioned previously. The difference

between observation and active conditions in preference for new-goal trials approached significance ($t(19) = 2.07, p = .05$). There was no significant difference between the observation and control conditions ($t(19) = 1.31, p = .20$).

In summary, Study 2 was designed to directly address the effects of passive experience on infants' developing action understanding. Results from this study failed to reveal any effect of passive experience on infants' understanding of a reach as goal-directed. None of the relations between active experience and looking times found in the active condition in Study 1 were replicated in this study with passive experience. Comparisons between this study and both conditions from Study 1 revealed that general responses of infants in the observation condition were more similar to infants in the control condition than the active condition.

General Discussion

The goal of these studies was to examine the effects of both active and passive experience on three-month-old infants' action understanding. Results from the control condition in Study 1 verified that, without experience producing object-directed actions with mittens, infants of this age do not view a mittened reach as object-directed. The active condition in Study 1 demonstrated that active experience leads infants of this age to understand another's grasp as goal-directed. The relationship between amount of active experience and action understanding replicated previous findings (Sommerville et al., 2005). Furthermore, this study shed new light on the relation between these two factors. The logarithmic function of the relationship indicates that the nature of the link between these two factors is best explained as a

threshold effect. Infants who received sufficient experience with mittens then understood another's grasp as goal-directed.

In Study 2, an additional group of infants received matched passive experience, undergoing training derived directly from the activity of infants in Study 1, in order to differentiate between the effects of active and passive experience. This study differs from previously conducted research in two important ways. First, it differs from the Sommerville et al. (2005) study in that it examines the unique contributions of active experience to action understanding. As discussed above, there are theoretical reasons to believe that active experience may provide a unique source of information. Although work by Sommerville and colleagues (in press) further supports this notion, the possibility that, early in the development of action understanding, observation provides information as well cannot be discounted, however.

A second way in which the current research differs from previous studies is that it examines the unique contributions of active experience at an age when action understanding is first emerging. The study by Sommerville et al. (in press) provides initial evidence that active experience uniquely contributes to action understanding. This study demonstrated that 10-month-old infants were able to learn about others' intentions in a sequence of actions through active experience but not through passive observation. It was unknown, however, whether active experience is uniquely important to intention understanding for younger infants. Though 10-month-old infants do not understand the end-goal of a means-end action without this active training, they do have an understanding of simple actions such as a basic grasp

(Woodward, 1998). The current study, however, examined three-month-old infants who have no foundational understanding of intentions upon which active experience can build.

Findings from our second study did not demonstrate any effect of passive experience on three-month-old infants' action understanding. A comparison of matched infants (with the top 75th percentile of experience) in the three conditions revealed a significant difference in looking time patterns as a function of condition. Study 1 demonstrated that infants without any experience with mittens did not understand another's action as goal-directed at this age. Study 2 revealed that, unlike active experience, passive experience did not influence infants' subsequent attention to the test events. Further, there was no hint of a threshold effect of passive experience (as was demonstrated in the active group in Study 1). In fact, even in considering those infants who received the highest amounts of passive experience, there was no consistency in their understanding of another's action (see Figure 3). In addition, in our studies, it could not have been that infants were simply more attentive to their own actions than another's, because our procedure ensured that infants in the observation condition were actively engaged throughout the session (only the time infants spent watching the mittened actions was counted as passive experience). The fact that active experience had a powerful effect above and beyond perceptual experience directly contradicts claims by Biro and Leslie (2006) that the knowledge gained by infants in Sommerville and colleagues' (2005) study was a function of these infants' experience viewing their own actions.

Whether active experience is qualitatively or quantitatively different from passive experience is an open question. In principle, it is possible that greater amounts of observational experience could influence infants' understanding of others' actions. Our findings do not rule out the possibility that observational experience is informative in later stages of development. In fact, we believe initial knowledge gained from active experience can be extended through passive experience and analogy (Gerson & Woodward, in press). Nothing in our findings, however, indicates that an effect of passive experience is present at this early stage of development.

Taken together, these findings suggests that active experience has a unique effect on infants' analysis of others' goal-directed actions. These results raise numerous questions concerning the means by which these effects occur. Several different proposals exist concerning how this link between self and others could occur. Some researchers have suggested a direct link between self and other, in the form of shared representations for one's own and others' actions (Hauf, Aschersleben, & Prinz, 2007; Meltzoff, 2005). This possibility is supported by findings indicating that there is a mirror system in humans that provides a direct link between action and perception, is selectively sensitive to goal-directed action, and is shaped by motor experience (Calvo-Merino, Grezes, Glaser, Passingham, & Haggard, 2006; Grezes & Decety, 2001; Iacoboni et al., 1999; Järveläinen, Schürmann, & Hari, 2004; Muthukumaraswamy, Johnson, & McNair, 2004). In contrast, others hypothesize that children extend information from self to others via a process of analogical mapping (e.g., Barresi & Moore, 1996). A third possibility is that both of these types of information sharing occur at different points during development

(Gerson & Woodward, in press). Future studies should be conducted to explore these possibilities.

An equally important question concerns whether the benefits gained from firsthand experience generalize across contexts. What is the range of events to which infants can extend their knowledge? Is infants' initial action understanding specific to the particular toys and action or are they broader? The breadth of this initial understanding holds great implications for learning and development in this domain. Current research in our laboratory is examining these important questions.

In sum, the current studies provide support for the proposal that self-produced actions provide unique information that is vital to the development of action understanding (Barresi & Moore, 1996; Gerson & Woodward, in press; Meltzoff, 2005; Tomasello, 1999; Woodward, 2005). As active agents in their own worlds, infants are naturally inclined to act in goal-directed ways, such as reaching for objects they intend to obtain, once they have the physical ability (Piaget, 1953; von Hofsten, 2004). All typically developing infants thus recruit this reliably present experience in order to inform their goal perception. In this way, self-produced action, like many other species-typical abilities, is an "experience-expectant" (Greenough et al., 1987) phenomenon that is necessary for the understanding of other agents' intentional actions. The organism itself (in this case, the human infant) can provide important information that guides experience and influences development. Considering the importance of experience-expectant processes allows us to move beyond the dichotomy between innate and environmental factors in order to more closely examine the meaningful interactions between them.

These findings also highlight the importance of cross-domain research in making progress toward our understanding of development. Researchers within the fields of motor development and conceptual development generally study progress within each of these domains without considering potential contributions from other areas of research (but see Cicchino & Rakison, in press; Perone, Madole, Ross-Sheehy, Carey, & Oakes, in press; von Hofsten, 2004 for some exceptions). Our findings demonstrate that the effects of learning in one domain (i.e., motor development) can have massive effects on learning in other domains (i.e., conceptual development). This type of cross-domain research can and should be extended across other areas of study in order to obtain a broader and more accurate view of development.

To conclude, the studies presented here provide new insights into the role of active experience in action understanding and also raise important questions to focus new directions of research. This research demonstrates that, at a time when infants are first able to understand others' intentional actions, "what's in a mitten," one's own or another's hand, matters; first-person experience uniquely benefits the understanding of others' intentional actions.

Footnotes

1. This reliability coding (looking times in test trials) is currently completed for eight of the infants in Study 1 and five of the infants in Study 2. This coding is ongoing and will be completed for all of the infants in both studies. All other reliability coding of these sessions has already been completed for all infants in both studies.
2. Although creating a proportion score raises the potential problem that data are non-normal, we conducted all analyses using the log of difference scores, which are not confined in the same way, and these analyses supported the same conclusions. Therefore, we include analyses using proportion scores as this seems an intuitive way to consider the data.
3. There were no cases in which average looking times to old- and new-goal trials did not differ by more than one second in either the active or control condition in Study 1.

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