A claw is like my hand: Comparison supports goal analysis in infants

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ABSTRACT

Understanding the intentional relations in others' actions is critical to human social life. Origins of this knowledge exist in the first year and are a function of both acting as an intentional agent and observing movement cues in actions. We explore a new mechanism we believe plays an important role in infants' understanding of new actions: comparison. We examine how the opportunity to compare a familiar action with a novel, tool use action helps 7- and 10-month-old infants extract and imitate the goal of a tool use action. Infants given the chance to compare their own reach for a toy with an experimenter's reach using a claw later imitated the goal of an experimenter's tool use action. Infants who engaged with the claw, were familiarized with the claw's causal properties, or learned the associations between claw and toys (but did not align their reaches with the claw's) did not imitate. Further, active participation in the familiar action to be compared was more beneficial than observing a familiar and novel action aligned for 10-month-olds. Infants' ability to extract the goal-relation of a novel action through comparison with a familiar action could have a broad impact on the development of action knowledge and social learning more generally.

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1. Introduction

When we see a child running towards her mother, a clerk reaching for a book on a shelf, or a gardener cutting a branch with pruning sheers, we automatically view these events not as purely physical movements through space, but as actions directed at and structured by goals. This perception of others' actions in terms of intentional relations is fundamental to human social life and foundational for cognitive, linguistic, and social development (Barresi & Moore, 1996).

The ability to discern intentional relations emerges early in life. By 3–6 months of age, infants show selective attention to the goal structure of action. For example, when viewing goal-directed actions, such as reaching for an object, in looking time experiments, infants attend more to changes in goals than changes in physical movements (e.g., Biro & Leslie, 2007; Luo & Johnson, 2009; Sommerville, Woodward, & Needham, 2005; Woodward, 1998; Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009). By the second half of the first year, this sensitivity to action goals is evident in infants' overt responses to others' actions. To illustrate, Hamlin and colleagues (Hamlin, Hallinan, & Woodward, 2008) showed 7-month-olds events in which an adult acted on one of two objects. When infants were given the opportunity to choose between the two objects, they systematically chose the adult's prior goal when the experimenter acted in a clearly intentional manner. In control conditions, Hamlin and colleagues demonstrated that infants' tendency to choose the adult's prior goal did not result from the way that the observed actions entrained infants' attention. Infants attended to the experimenter's toy choice both when the experimenter grasped the object and when she acted on the object in an unusual or unfamiliar manner (e.g., touching the toy with the back of her hand); they only imitated, however, when the experimenter's action was interpretable as goal-directed (i.e., when she grasped). Thus, 7-

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month-old infants reproduced the goal-relevant aspects of the actions they had observed (see also Mahajan & Woodward, 2009).

Intentional relations structure concrete actions, such as reaching for a book, as well as more abstract and complex connections between agents and their goals, such as using tools to act on distant objects. Although by the second year after birth children can flexibly interpret others' actions, even when they are novel or complex (e.g., Meltzoff, 1995), a number of findings indicate limits in younger infants' abilities to fluently identify the intentional structure of complex actions (see Woodward et al. (2009) for a review). For example, although looking time studies have shown that infants are sensitive to the goal-structure of reaching by 6 months (Woodward, 1998), when these studies involve tool use, infants under 12 months do not readily recognize the experimenter's actions as organized with respect to the goal (e.g., Cannon & Woodward, 2010; Jovanovic et al., 2007; Sommerville & Woodward, 2005). Tool use is ubiquitous in everyday social environments, yet it may pose a conceptual challenge to infants. Tool use actions are complex – the agent's contact with the tool is not directed at the tool itself but at the object on which it acts. Further, these events may involve tools that are novel to infants.

These points highlight one example of a more general developmental challenge: how do infants become able to discern the goal structure of novel, complex actions? Two sources of information have been hypothesized to address this challenge. First, information provided by the visible movements of agents has been shown to influence infants' goal analysis, for example, when potential agents exhibit rational or repeated movements toward a goal (e.g., Biro & Leslie, 2007; Gergely & Csibra, 2003). Even so, younger infants seem less sensitive to these cues as a source of information about tool use events than do older infants. For example, Hofer and colleagues (Hofer, Hauf, & Aschersleben, 2005) found that including information about the effects of a novel tool use action supported 12-month-old infants' ability to see the action as goal-directed, but these same cues did not influence 9-month-old infants' interpretation of the event. Similarly, Biro and Leslie (2007) found that including multiple movement cues supported infants' interpretation of tool use events, but that younger infants did not respond systematically unless many cues were present in both familiarization and test phases of the experiment (see also Cannon & Woodward, 2010; Jovanovic et al., 2007).

A second source of information has been shown to derive from infants' own actions. When infants are trained to produce novel actions (such as using a tool to obtain a toy), they subsequently detect the goal-structure in these same actions performed by others (Sommerville, Hildebrand, & Crane, 2008; Sommerville et al., 2005). Thus, action experience supports infants' learning about the goal-structure of action. However, because infants are often confronted with actions they have never performed themselves, this information is also of limited value.

We consider a third source of information that could provide further support for infants' analysis of novel actions. Specifically, we examine whether comparisons between familiar and novel actions contribute to infants' interpretation of novel actions. To use information about a familiar action to make sense of a novel one, individuals must detect the relational similarity between the two events. They must understand that the relation between the agent and his goal defines both the familiar and the novel action. Structural alignment could support this process. When two instances are aligned, one can compare the commonalities and differences and extract the structural (i.e., relational) similarities between exemplars (Gentner, 2003). When the relational structure of one instance is known, it can serve as a base for analogical extension, supporting the inference of similar relational structure in a novel instance with which the known example has been aligned (Gentner & Medina, 1998).

The power of comparison processes in supporting cognitive learning has been well documented in both children and adults. Across a number of cognitive domains, opportunities to compare exemplars have been shown to facilitate the detection of relational properties and the extension of this analysis to new instances. For example, comparison has been shown to support reasoning about spatial relations in young children, helping them to see that two different scenes can be viewed in terms of spatial relations like "under" or "on" (e.g., Loewenstein & Gentner, 2001). Several factors facilitate comparison, including the simultaneous presentation of exemplars, the use of language to highlight similarities across exemplars, the surface similarity of exemplars, and progressive presentation of similar to dissimilar exemplars (e.g., Christie & Gentner, 2010; Kotovsky & Gentner, 1996; Loewenstein & Gentner, 2001, 2005; Namy & Gentner, 2002). The construction of an *explicit* analogy is not required in order to benefit from comparison. Comparison can highlight relational similarities in very young children and even in infants.

Burgeoning evidence indicates that comparison processes operate during infancy and support infants' detection of relations and relational similarity. For example, Chen and colleagues (Chen, Sanchez, & Campbell, 1997) examined infants' ability to extend knowledge about one means-end problem to a new problem. They found that the opportunity to compare similar tool use problems helped 10- and 13-month-old infants extract the causal relations necessary to performing the task and extend a solution to novel problems. Other findings suggest that similar processes may operate in physical reasoning (Baillargeon & Wang, 2002) and verb learning (Childers, 2008). Moreover, comparison has been shown to support infants' analysis of non-relational information in the domains of categorization (Oakes, Kovack-Lesh, & Horst, 2009) and object individuation (Wilcox, Smith, & Woods, 2010).

Pruden and colleagues (Pruden, Hirsh-Pasek, Maguire, & Meyer, 2004; Pruden, Shallcross, Hirsh-Pasek, & Golinkoff, 2008) demonstrated that simultaneous comparison supported infants' ability to extract relational information about actions. In this line of research, Pruden and colleagues examined 7- to 9-month-old infants' ability to detect similarities in events in which an object moved on a specific path with respect to a landmark (e.g., passing over versus under a dot on the screen). They found that simultaneous presentation of actions matching in path (e.g., over

rather than under a dot on a screen) but differing in manner (e.g., jumping versus spinning) allowed infants to detect the similarity in the path of movement in relation to the landmark. In contrast, consecutively presented actions did not have this effect initially. Taken together, these findings suggest that young infants can use comparison processes to extract relational information and their ability to do so is influenced by the same factors as in older children and adults.

It has been proposed that similar processes operate in infants' social cognitive development. In a seminal theoretical paper, Barresi and Moore (1996) formulated an account of how comparison could support analogical insights in the context of joint attention. During joint attention, the infant's intentional actions are physically copresent with and directed at the same object as the adult. Barresi and Moore hypothesized that this physical alignment of the infant's and adult's observable actions and attentional states during joint attention allows infants to compare their own acts of attention with others' and therefore gain insight into others' attentional states (see Meltzoff (2005) and Tomasello and Moll (2010) for related proposals). Although it may be possible to gain insights from comparing the actions of observed social partners to one another, Barresi and Moore (1996) hypothesize that comparison to oneself is particularly informative because it enables infants to draw on their own experience in attending to objects for understanding others' states of attention.

Several recent findings are consistent with the hypothesis that joint attention plays a role in social information processing. For one, the presence of joint attention supports infants' attention to objects and emotions during social interactions (e.g., Hoehl et al., 2009; Lavelli & Fogel, 2005). Moreover, research by Moll and colleagues (Moll, Carpenter, & Tomasello, 2007) suggests that infants learn about others' knowledge states from participation in joint engagement before they are able to extract this same information from observing social partners jointly engaged in play with an object. In a series of studies, 14-month-old infants either engaged in joint play toward a toy with an experimenter or observed two experimenters jointly playing with the toy. Infants were later able to identify which toy the experimenter had previously seen only in the case in which they had actively participated in joint engagement with the experimenter and not when they had observed the experimenter engaged in play with another social partner. Tomasello and Moll (2010) concluded from these findings that participating in collaborative interactions with "shared intentionality" allows an infant to create "perspectival" cognitive representations and "conceptualize the interaction simultaneously both from the first and third person's perspective" (p. 344).

Together, these findings, and the theories in which they are grounded, suggest that comparison processes may support older infants' understanding of others' focus of attention, though they do not provide direct evidence for this claim. In the current studies, we sought further evidence for the role of comparison in supporting infants' action analysis by asking whether engagement in alignment and comparison supports younger infants' understanding of novel goal-directed actions, in this case, tool use. Specifically, we tested whether allowing infants to simultaneously align a familiar action (their own grasp) with another person's tool use action would enable them to understand the goal structure of the tool use action.

Across experiments, we used the goal imitation paradigm developed by Hamlin and colleagues (2008) as a measure of action understanding. In this paradigm, 7-month-old infants systematically select an experimenter's prior goal, but only when the modeled action is one that they recognize as goal-directed (e.g., grasping but not back of hand touching). As a point of clarification, in this paradigm, goal imitation refers to recognizing and choosing the same *goal* as the experimenter. In contrast to other interpretations of the term imitation, our use of the term does not require imitation of the exact action (and action style) produced by the experimenter in order to achieve her goal. In fact, infants never had the opportunity to act on the toys with the tool in any of the following studies. Instead, we examined goal imitation (choosing the same toy as the experimenter by intentionally touching it) as a measure of recognition of the goal of the experimenter's action.

In the current studies, infants saw an experimenter grasp an object with a claw, an event we predicted 7-month-olds would not spontaneously understand as goal-directed. We then evaluated whether giving infants the opportunity to align their own grasping actions with this novel tool use action would provide them with insight into its goal-structure. In Study 1, prior to viewing the tool use events in the goal imitation paradigm, infants in the *physical alignment condition* were given the opportunity to reach for objects held by the claw, and thus align their goal-directed actions with those of the experimenter using the claw. We predicted that this experience would support infants' understanding of the tool use actions as goal-directed. To evaluate whether alignment per se was critical for this effect, we tested additional groups of infants in two control conditions in which infants interacted with the claw with no objects present (*control touch condition*) or were shown the functional properties of the claw (*control move condition*). In Study 2, we conducted a further control (*control association condition*) to evaluate positive findings in the first experiment. In Study 3, we asked whether alignment of one's own actions is particularly informative about the goal structure of action, or whether, instead, similar insights are provided by observing aligned instances in others' actions.

2. Study 1

2.1. Methods

2.1.1. Participants

Sixty full-term 7-month-old infants (6.5–7.5 months) participated in this study. Infants were recruited from the Washington, DC metropolitan area through mailings and advertisements. Twenty additional infants began the study but were not included in final analyses due to side preference ($n = 11$; i.e., only reaching to one side of the tray across test trials), or inactivity (i.e., not acting on either

toy for more than half of the test trials) or inability to complete the procedure due to crying ($n = 9$). The sample of infants was 53% Caucasian, 20% African–American, 12% multiracial, 10% Hispanic, and 5% unreported. Twenty infants participated in each of three conditions: physical alignment (10 boys; M age = 6;28), control touch (10 boys; M age = 6;27), and control move (9 boys; M age = 6;24).

2.1.2. Procedure

In this and all following studies, infants sat on a parent's lap at a table across from an experimenter. Parents were told not to influence their infant's actions in any way by talking, pointing, or generally interfering. A camera behind the experimenter focused on the infant and a camera behind the infant focused on the event. These recordings were then used for offline coding.

Infants were first familiarized with the twelve toys used during the experiment, presented one at a time in randomized order, on alternating sides of a 76 cm × 23 cm tray. The familiarization phase differed across the three conditions (see Fig. 1). In the physical alignment condition an experimenter passed infants each toy consecutively with the claw and then retrieved the previous toy from the infants with her hand before passing the next toy with the claw. This allowed infants to physically align their reaches with the experimenter's grasp of the toy with the claw. Infants did so on approximately 87% of the 12 trials.

In the control conditions, the experimenter passed infants the toys with her hand rather than using the claw (so all infants were familiarized with all toys). Then, infants in the two conditions received different exposure to the claw before test trials. In the control touch condition, the experimenter held and opened and closed the claw and allowed infants to interact with it for approximately 20 s. Thus, infants were familiarized with the claw and could see that an adult who interacted with them held it, but, because no toy was present, they could not align their object-directed actions with those of the experimenter using the claw. Infants in the control move condition watched the experimenter move each of the toys across the table with the claw. Thus, they saw the claw's functional properties and that an adult held it, but they were not able to align their own actions with the experimenter's.

After familiarization, all infants underwent the same goal imitation procedure. A pair of toys were placed 28 cm apart on the tray and placed in front of the experimenter. The experimenter first ensured infants saw both toys. She then made eye contact with the infant and said, "Hi! Look!" and shifted her gaze toward the goal toy as she reached contralaterally for the toy using the claw (see Fig. 2). The experimenter grasped the toy with the claw but did not pick up or move the toy. She gazed at the toy throughout the grasp and said "Oooh!" twice. The experimenter then withdrew the claw and established eye contact again, bringing the infant's attention back to center. She then pushed the tray to the infant and said, "Now it's your turn!" The experimenter pulled the tray back after the infant chose a toy or after approximately 30 s if the infant did not act.

This procedure was repeated six times with a new pair of toys presented at each trial. The experimenter alternated reaching to her left or right. Within each condition, each toy was reached for equally, and side of presentation and side of first reach was counterbalanced across infants. The order of the pairs was randomized.

2.1.3. Coding

Observers who were unaware of the assigned condition and the experimenter's goal on each trial coded infants' toy selection offline using a digitized video. The infant's choice was coded as the first toy she touched so long as the touch was preceded by visual contact. If the infant touched a toy without looking and this subsequently drew the infant's attention to the toy, this was coded as a mistrial. A second independent coder scored all of the infants, and the two coders agreed on 95% of the trials. In a second pass, infants' visual attention to the claw, toy, and experimenter during familiarization and test trial demonstrations was coded using a digital coding program (Mangold, 1998). Five infants were not coded for attention due to equipment error (two in the physical alignment condition, one in the control touch condition, and two in the control move condition). A second independent coder coded 25% of the infants' familiarization and test-trials and the two coders' judgments were strongly correlated ($rs > .90$).

2.2. Results

Focal analyses examined the proportion of trials on which infants chose the experimenter's goal toy. Preliminary analyses indicated that infants' responses did not vary across trials, $ps > .45$, so average goal imitation across all six test trials was used in all analyses. The number of trials for which infants produced intentional first touches (rather
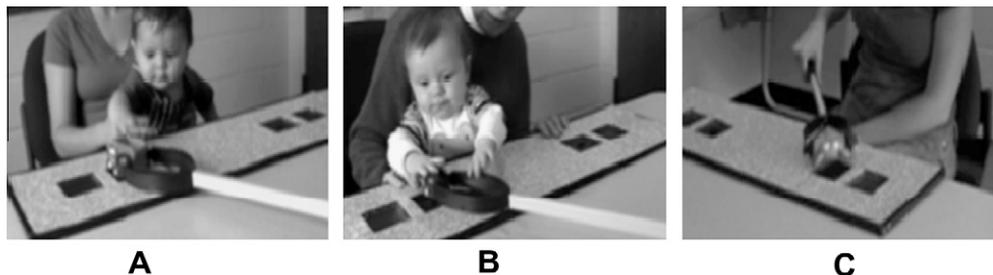

Fig. 1. Familiarization events in Study 1 for the physical alignment condition (A), control touch condition (B), and control move condition (C).
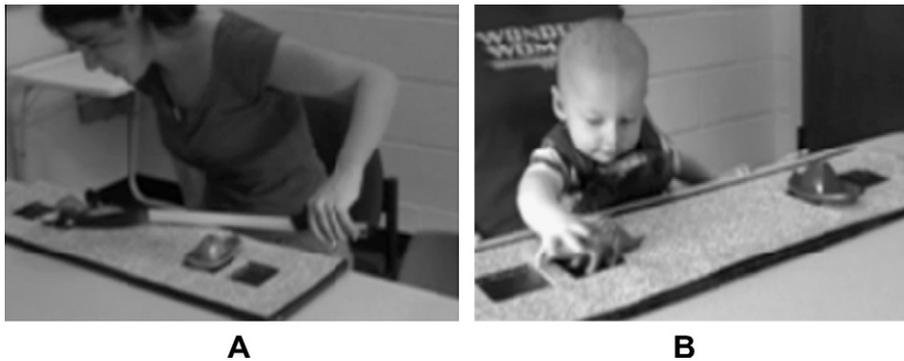
Fig. 2. Test trial events in all conditions and all studies: demonstration (A) toy choice (B).

than mistrials or lack of activity) did not differ between conditions (82%, 78%, and 81% of trials in the physical alignment, control touch, and control move conditions, respectively). Assumptions of normality and homogeneity of variance were met for this and all following studies, Levene's statistic <1.12, ns; Kolmogorov–Smirnov $Z \leqslant 1.2$, ns. Preliminary analyses indicated no effects of gender, so it was not included in further analyses. A one-way ANOVA indicated that infants' toy choices differed by condition, $F(2,57) = 3.96$, $p = .024$; $\eta_p^2 = .12$ (see Fig. 3).

Due to our hypothesis that infants in the physical alignment condition would imitate more than infants in either control condition, a priori tests were conducted using LSD to evaluate pairwise differences among the means. As expected, these comparisons revealed that infants in the physical alignment condition chose the goal toy significantly more often than infants in both the control touch, mean difference = .14; $p = .035$, and control move, mean difference = .17; $p = .011$, conditions. Furthermore, infants in the physical alignment condition selected the goal toy more often than would be expected by chance, $t(19) = 2.61$, $p = .02$. Infants in the control conditions did not differ from chance in their choices, $ts < 1$; $ps > .3$. Thus, infants who aligned their actions and goals with the experimenter's (using the claw) subsequently imitated the goal of the experimenter's tool use actions, but infants familiarized with the claw and its functional movements did not.

In follow-up analyses, we evaluated whether differences in infants' responses could be attributed to lower level effects of familiarization on infants' attention to the toys, experimenter, or claw. We first verified that infants' attention to the experimenter and the goal toy during test trial demonstrations did not differ across conditions. One-way ANOVAs indicated that attention to the goal and experimenter did not differ, $ps > .4$. In each condition, infants spent significantly more time attending to the experimenter's goal than the non-goal, $ps < .03$ (see Fig. 4). Moreover, attention to the experimenter's goal or to the experimenter during test trial demonstrations was not related to goal imitation in any condition, $ps > .2$.

Next, we asked whether differences in attention during familiarization influenced behavior during goal imitation. In particular, we wondered whether the physical alignment condition supported infants' goal imitation simply because it led to increased attention to the claw or experimenter prior to test trials. There were differences across conditions in infants' attention to the claw, $F(2,52) = 28.34$, $p < .001$, but these differences did not coincide with systematic performance on goal imitation. Infants in the control move condition attended most to the claw ($M = 29.16$ s, $SD = 3.80$), infants in the control touch condition attended least ($M = 16.84$ s, $SD = 3.14$), and infants in the physical alignment condition fell between these two ($M = 23.55$, $SD = 7.16$).

Furthermore, attention to the claw was not related to infants' rates of goal imitation in any condition, $ps > .69$. Infants' attention to the experimenter during familiarization did not vary as a function of condition, $F(2,52) = .94$,
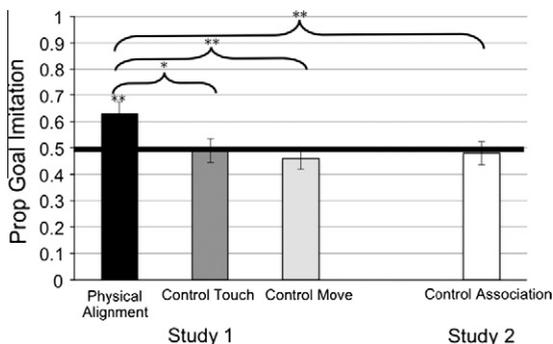

Fig. 3. Proportion of test trials infants imitated in Studies 1 and 2. $^{**}p < .02$, $^*p < .05$.

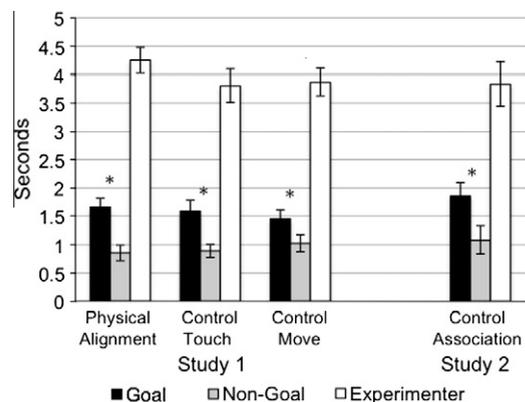**Fig. 4.** Infants' attention to test trial demonstrations in Studies 1 and 2. $^*p$'s < 0.3.

$p = .40$, and was not related to goal imitation, $ps > .05$. Thus, we found no evidence that differences between infants' responses in the different conditions resulted from differences in how their attention was directed during either test trial demonstrations or familiarization.

2.3. Discussion

We asked whether infants could use knowledge about a familiar action to make sense of a novel one. Results suggest they can. As in prior studies, the current findings indicate that young infants have difficulty discerning the goals of tool use actions. When infants first aligned their actions with the experimenter's tool use actions, however, they subsequently responded selectively to the goal structure of the tool use event. Specifically, infants who had acted simultaneously on a toy with the experimenter (using a claw) later imitated the goal of the experimenter's tool use actions. Because the infant and experimenter acted on each toy during physical alignment training, infants' toy selection during test trials could not be due to reinforcement of actions on particular objects. Rather, physical alignment training provided infants with information about the experimenter's actions they then used during goal imitation trials.

There were several cues in the physical alignment condition that could have supported infants' goal analysis but the findings of the control conditions suggest that physical alignment per se was critical for this effect. In each condition, infants saw an experimenter coordinate her attention and actions on the objects she reached for with the claw during test trials. To adults, coordinating one's gaze and manual activity on a particular object provides clear evidence that the claw movements are goal-directed. Previous research indicates that older infants can use these kinds of person-centered cues to interpret actions as goal-directed (Hofer et al., 2005), but no existing evidence indicates that these cues are sufficient for goal interpretation in 7-month-old infants. Given the negative findings in the two control conditions, person-centered cues seemed not to drive infants' goal analysis in the current study either.

Similarly, demonstration of the functional affordances of a tool (i.e., movement cues) have also been shown to support older infants' interpretation of tool use actions, but these cues seem less effective in infants younger than 12 months (Cannon & Woodward, 2010; Hofer et al., 2005; Jovanovic et al., 2007). The control move condition showed infants that the experimenter could move objects with the claw. Lack of systematic responses in this condition suggests that movement cues were not sufficient to drive 7-month-olds' goal analysis in this study. Our findings suggest that physical alignment between infants' own, familiar action, and the novel action, played the critical role in supporting infants' analysis of the novel action as goal-directed.

Despite these controls, an alternative explanation concerning infants' goal imitation in the physical alignment condition remains. In this condition, infants saw iterative presentations of the claw holding the toy, after which they we able to grasp the toy held by the claw. This association between the claw and the subsequent opportunity to engage with the toy might have led infants to choose the toy with which the claw was associated in each test trial. In order to evaluate this alternative explanation for the findings, we conducted a second study in which infants were given the opportunity to grasp toys that were held by the claw during familiarization, but the claw was not used as a tool by the experimenter. Thus, the contingency between seeing the claw and receiving the toy was the same as in the physical alignment condition of Study 1, but this experience did not occur in the context of infants' actions (and goals) being aligned with those of the experimenter.

3. Study 2

3.1. Methods

3.1.1. Participants

Twenty full-term 7-month-old infants (6.5–7.5 months) participated in this study (10 males; M age = 7;1). Eight additional infants began the study but were not included in final analyses due to side preference ($n = 7$), or inactivity or inability to complete the procedure due to crying ($n = 1$). The sample of infants was 45% Caucasian, 25% Hispanic, 15% African–American, 10% multiracial, and 5% Asian.

3.1.2. Procedure

Infants were familiarized to both the claw and each toy by being passed the mat 12 times (once for each toy), on which both a toy and the claw rested (see Fig. 5). The claw was secured to the mat so the infant could not pick it up. The toy, however, was free for the infant to grasp and/or pick up. If infants did not immediately attend to the toy, the experimenter drew the infant's attention to the toy by tapping near it. This gave infants the opportunity to associate the claw with each toy without the chance to compare the experimenter's goal when using the claw with their own goal (because the experimenter did not hold the claw during familiarization trials in this condition). Immediately after familiarization, infants underwent the same exact test trials as infants in Study 1. Coders assessed infants' toy-choice (a second, reliability coder agreed on 96% of trials) and measured infants' attention to the claw, toys, and experimenter during both test trials (two coders' judgments were strongly correlated; $r > .98$) and familiar-

Fig. 5. Familiarization events in Study 2.

ization (two coders' judgments were strongly correlated; $r > .97$). Three infants were not coded for attention during test-trials due to equipment error.

3.2. Results

As in Study 1, infants' responses did not change across test trials (p's > .18); infants produced an intentional touch on 91% of trials. Focal analysis concerned whether infants imitated the experimenter's goal significantly more often than would be expected by chance. A one-sample t-test indicated that infants in Study 2 did not differ from chance in their imitation of the experimenter's goal, $t(19) = .53$, $p = .60$. Additionally, infants in Study 2 differed significantly from infants in the physical alignment condition from Study 1 in their goal imitation, $t(38) = 2.31$, $p = .025$ (see Fig. 3).

As in Study 1, infants spent significantly more time attending to the experimenter's goal than the non-goal, $p < .001$ (see Fig. 4). Additionally, neither attention to the experimenter nor to her goal during test trial demonstrations was related to infants' goal imitation, $ps > .27$. Finally, attention to the event and attention to the experimenter during familiarization trials were not related to goal imitation, $ps > .17$.

3.3. Discussion

The findings from this study demonstrate that an association between claw and toy was not driving infants' goal imitation in the physical alignment condition in Study 1. In Study 2, infants had the chance to associate each toy they played with in familiarization with the claw but this did not lead them to choose the toy paired with the claw in test trial demonstrations. This supports the conclusion that infants in the physical alignment condition in Study 1 did more than merely form an association between the claw and the toys. Instead, they extracted the relevant goal information and used this information to guide their toy selection. Together with the findings of Study 1, these results indicate that physical alignment supports 7-month-old infants' analysis of novel actions as goal-directed.

4. Study 3

As noted in the introduction, it has been hypothesized that comparisons involving ones own actions are particularly informative in the social domain (Barresi & Moore, 1996; Meltzoff, 2005; Moll et al., 2007; Tomasello & Moll, 2010). Consistent with this hypothesis, training studies indicate that production of novel actions (but not observation of these same actions) supports infants' interpretation of others' actions as goal-directed (Sommerville et al., 2005, 2008). These considerations suggest that in the current context, alignment of novel tool use actions with infants' own actions may be particularly informative. On the other hand, evidence indicates that children can benefit from comparison of exemplars external to themselves (Gentner, 2003).

In Study 3, we addressed the question of whether active engagement in physical alignment is uniquely beneficial above and beyond observation of physical alignment. We examined the effects of aligning novel goal-directed actions with one's own goal-directed actions relative to the effects of observing others' aligned (novel and familiar) actions. We tested 10-month-old infants in this study because, although evidence concerning infants' detection of relational similarity through comparison is limited, the best evidence that exists suggests that by 10 months, infants can sometimes extract relational similarity from observed instances (Chen et al., 1997; Pruden et al., 2004). Further, like 7-month-olds, infants at this age do not show robust understanding of tool use actions as goal-directed (Cannon & Woodward, 2010; Hofer et al., 2005; Sommerville & Woodward, 2005; Sommerville et al., 2008).

Infants participated in one of two conditions. One group of infants was given the chance to actively engage in physical alignment (*active condition*). This was a direct replication of the physical alignment condition in Study 1 with 10-month-old infants and allowed us to see whether 10-month-old infants would systematically benefit from this paradigm, as did 7-month-olds. In a second condition (*observational condition*), infants had the chance to observe the same events. These infants viewed the experimenter pass each of the toys to a second experimenter using the claw. This gave infants the opportunity to observe the physical alignment of a familiar (grasp) and novel (tool use) action.

4.1. Methods

4.1.1. Participants

Thirty-two full-term 10-month-old infants (9.5–10.5 months) participated in this study. Sixteen infants participated in the active condition (eight males; M age = 9;28) and 16 participated in the observational condition (seven males; M age = 9;25). Ten additional infants began the study but were not included in final analyses due to side preference ($n = 8$), inactivity or inability to complete the procedure due to crying ($n = 1$), or parental interference ($n = 1$). The sample of infants was 52% Caucasian, 25% African–American, 8% Hispanic, 8% multiracial, 5% unreported, and 2% Asian.

4.1.2. Procedure

The procedure for the active condition exactly matched the procedure for the physical alignment condition in Study 1. Infants in the active condition aligned their reaches with the claw's reach for the toy on approximately 70% of the 12 trials. The observational condition took place in the same room with the same materials and set-up. The familiarization phase in the observational condition began with the experimenter passing the infant each of the toys on alternate sides of the tray (as in the control conditions in Study 1). After infants saw each of the toys, a second experimenter (E2) then appeared to the first experimenter's (E1) right. E1 passed each toy to E2 using the claw (see Fig. 6). E2 grasped the toy with her hand and said "thanks" (or thank you) in an excited tone in order to engage the infants' attention. She looked back and forth be-

Fig. 6. Familiarization events in Study 3 (observational condition).

Fig. 7. Proportion of test trials infants imitated in Study 3. $^*p \leqslant .01$.

tween the toy and the infant. If the infant was not attending at the beginning of her movement, E1 tapped near the toy or said "hi" or "look" to the infant. In this way, it was ensured that the infant observed the physical alignment of E1's grasp for the toy with the tool and E2's grasp for the toy with her hand. Following this familiarization, E2 left the room, and the test trials we conducted as in Studies 1 and 2. As in Studies 1 and 2, coders assessed infants' toy-choice (a second, reliability coder agreed on 96% of trials) and measured infants' attention to the claw, toys, and experimenter(s) during both test trials (two coders' judgments were strongly correlated; rs > .96) and familiarization (two coders' judgments were strongly correlated; rs > .95). Two infants could not be coded for attention during familiarization because of equipment error.

4.2. Results

Our primary analysis again concerned the proportion of trials on which infants chose the experimenter's goal toy. As before, infants' responses did not change across trials, ps > .22, so average goal imitation across all six test trials was used in all analyses. The number of trials for which infants produced intentional first touches (rather than mistrials or lack of activity) did not differ between conditions (96% and 91% in active and observational conditions, respectively). An independent samples t-test indicated that infants in the active and observational conditions were significantly different from one another in their imitation of the experimenter's goals, $t(30) = 2.44$, $p = .02$, Cohen's $d = .87$ (see Fig. 7). Infants in the active condition chose the experimenter's goal significantly more than would be predicted by chance, $t(15) = 2.19$, $p = .045$. This replicates the findings from Study 1. In fact, 7-month-old infants in Study 1 and 10-month-old infants in the active condition in this study both imitated the experimenter's goal on approximately 63% of test trials, $t(34) = .026$, $p = .98$. In contrast, infants in the observational condition did not differ from chance in their goal imitation, $t(15) = -1.24$, $p = .23$.

We again examined infants' attention during both the test trials and familiarization period. As in Study 1, attention to the goal and experimenter during test trial demonstrations did not differ between conditions, ps > .15. In
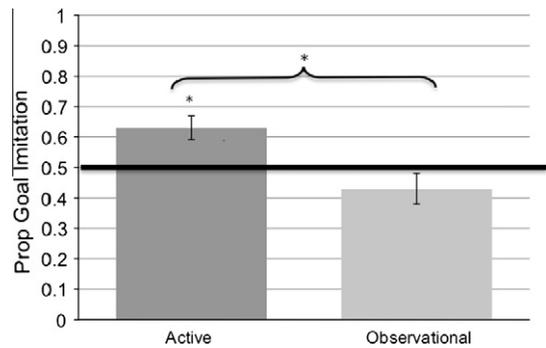
both conditions, infants spent significantly more time attending to the experimenter's goal than the non-goal, ps < .001 (see Fig. 8). Additionally, neither attention to the experimenter or to her goal was related to infants' goal imitation, ps > .09.

Finally, we examined infants' attention to the experimenter and events during familiarization. Infants in the active and observational conditions did not differ significantly in their attention to the claw and its actions, $t(28) = .69$; $p = .50$. They did differ, however, in their attention to the experimenter(s). Not surprisingly, infants in the observational condition spent significantly more time looking at the two experimenters than the infants in the active condition spent looking at the one experimenter, $t(26.56) = 3.22$; $p = .003$. Neither attention to the event or attention to the experimenter(s), however, was related to goal imitation in either condition, ps > .19.

4.3. Discussion

The findings in the active condition replicated those from the physical alignment condition in Study 1. After the opportunity to simultaneously compare their own, familiar, action with a novel tool use action, infants responded systematically to the goal structure of the experimenter's tool use actions in the goal imitation paradigm. These findings support the conclusion that comparison with their own actions supports 10-month-old infants'
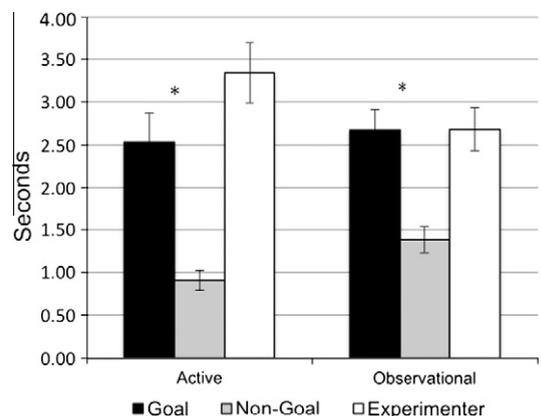

Fig. 8. Infants' attention to test trial demonstrations in Study 3. $^*p \leqslant .002$.

understanding of others' tool use actions as goal-directed. The findings in the observational condition suggest that comparisons between the observed actions of two other people are less informative for infants at this age. Infants in the observational condition viewed aligned examples of a familiar action, grasping, and a novel action, tool use. They were highly attentive to these examples, looking as long or longer at them than at the analogous examples in the active condition. Nevertheless, infants in the observational condition seemed not to benefit from this experience when they subsequently viewed tool use action in the goal imitation paradigm. These findings are consistent with other results indicating that first person engagement in actions provides more robust support for understanding others' states of attention (Moll et al., 2007) and for learning about the goal structure of novel instrumental actions (Sommerville et al., 2008).

As in Study 1, the observational condition provided both person-centered and object-movement cues that could have aided infants' interpretation of the event. Although movement cues in combination with cues indicating that a human is acting on the tool helped 9-month-olds interpret a tool use action as goal-directed in Hofer and colleagues' study (Hofer et al., 2005), we found that these cues were not sufficient for 10-month-olds' imitation of tool use actions in the current paradigm. One possible reason for this inconsistency is that the interactions in the current studies may have seemed more complex to infants. In addition, infants' responses in Hofer and colleagues' study could have been influenced by a confound in the paradigm, the presence of movement during test trials (see Heineman-Pieper & Woodward, 2003). When this confound is eliminated, cues that a person is present seem less effective (Cannon & Woodward, 2010).

The fact that infants did not benefit from simultaneous comparison of two observed exemplars stands in contrast to findings reviewed in the introduction suggesting that infants can extract and generalize relations through comparisons that are external to the self in domains like problem solving and spatial reasoning (e.g., Chen et al., 1997; Pruden et al., 2004, 2008). This raises the question as to whether the benefit of active engagement in analogy is unique to the social domain. As discussed earlier, several researchers have suggested that comparisons between the self and other are critical to learning about the goals and actions of others because the first person perspective provides clearer, or more robust information about the intentional relations that structure one's actions (Barresi & Moore, 1996; Meltzoff, 2005; Tomasello, 1999).

Although active engagement in analogy may be uniquely beneficial at the origins of its application to action understanding, it is possible that comparison of observed exemplars supports learning about intentional action at later points in development. Future studies should consider what mechanisms might play a role in this kind of development.

5. General discussion

In the current studies we asked whether infants gain insight into the goal structure of other people's actions by comparing these actions with their own. Because comparison has been shown to support the detection of relational similarities in both young children and in infants, we hypothesized that providing support for comparison would enable infants to see the analogy between their own goal-directed action and a novel tool use action performed by another person. Our findings indicate that this occurred. When 7-month-old (in Study 1) and 10-month-old (in Study 3) infants had the opportunity to align their own reach with a tool use action performed by an adult, so that the two actions were directed at the same goal at the same time, they subsequently showed an understanding of that action as goal-directed, systematically reproducing the goal of actions performed by the experimenter with the tool.

Analyses of infants' attention during the familiarization and test trials across studies and conditions indicated that infants' systematic responses during goal imitation trials could not be accounted for by how the procedure entrained infants' attention in the critical conditions. Moreover, Study 2 evaluated, and ruled out, the possibility that infants' choice of the goal object in the alignment conditions was due to a conditioned response to choose the toy that had been associated with the claw. Instead, we conclude that infants' responses to the alignment conditions were driven by information it provided them about the tool use action.

Even so, the manipulation that allowed infants to align their own actions with the novel action involved several elements that could have influenced infants' understanding of the tool's actions. To start, infants saw the experimenter who manipulated the tool, and could see that she coordinated her gaze with her actions. Associating a human agent with the tool action has been shown to contribute to infants' action understanding in some cases (Hofer et al., 2005) and coordinated gaze has also been shown to influence infants' goal recognition in some cases (Luo & Baillargeon, 2005; Luo & Johnson, 2009; though see Sommerville & Woodward, 2005; Sommerville et al., 2008). The infants tested in the current studies, however, seemed not to benefit from these cues, which were present in each of the control conditions and did not, on their own, affect infants' response to the tool actions.

During alignment, infants also engaged socially with the experimenter, and social contingency has been shown to support goal attribution in older infants (Johnson, Shimizu, & Ok, 2007). However, this factor, on its own, was not sufficient to support infants' understanding of the experimenter's tool use actions. Infants engaged socially with the experimenter in the control touch condition in Study 1 and they viewed the experimenter engaging socially with another adult in the observational condition in Study 3, but in neither case did this lead infants to understand the tool use action as goal-directed.

Further, while aligning their own actions with the tool use actions, infants saw the tool move the object. It has been hypothesized that "action effects" such as contact that results in movement, sometimes leads infants to view the contacting action as goal-directed (Biro & Leslie, 2007; Hofer et al., 2005; Jovanovic et al., 2007). However, action effects were also present in the control move condition in

Study 1 and the observational condition in Study 3, and in neither of these conditions did infants respond systematically to the tool use actions in test trials. Action effects appear to have a stronger effect on older infants' than younger infants' responses to novel actions that involve tools (Biro & Leslie, 2007; Hofer et al., 2005; Jovanovic et al., 2007). The current findings with 7- and 10-month-olds are consistent with this pattern.

A final source of evidence that has been shown to influence infants' interpretation of goal-directed action is whether the action seems rational with respect to the constraints in the context (e.g., Gergely & Csibra, 2003). Although this is true, again, the conditions in the current condition did not differ in their apparent rationality. The test demonstrations were identical across all conditions and all experiments; the rationality of these events could not have contributed to differential responses across conditions. Is it possible that differences in the apparent rationality in the familiarization events could have contributed? In the physical alignment and active conditions, infants received mixed evidence about the rationality of the action. Although the experimenter used the claw to hand the infant the toy across the table, she demonstrated on each trial that she could reach across the table without the claw when she retrieved the toy from the infant with her hand. Thus, if anything, this might have made the actions more difficult for infants to understand because the use of the tool was not in response to an environmental constraint.

As this discussion illustrates, the current literature has revealed a number of sources of evidence that contribute to infants' understanding of actions as goal-directed. Many of these cues work in some contexts, but mixed findings leave many open questions as to when and how they contribute. Our findings identify another source of information that contributes to infants' analysis of goal-directed action, namely, comparison of novel actions with their own goal-directed actions.

Taken together, infants' responses across studies and conditions indicate that it was alignment of their own actions with the tool use action that was critical for their subsequent understanding of the tool action as goal-directed. More generally, consistent with several theoretical proposals (e.g., Barresi & Moore, 1996; Meltzoff, 2005; Tomasello, 1999), the current findings suggest that conditions that promote comparison of infants' own actions with those of others are particularly informative for infants' understanding of others' goals. Because the critical information that infants would derive from such comparisons is relational in nature, namely that an action is directed toward a goal, we conclude that comparison facilitated infants' detection of relational similarities between their own actions and the experimenter's claw actions. That is, we propose that physical alignment supported infants' interpretation of the tool use events because it helped them see the analogy between their own goal-directed actions and those of the experimenter using the claw. As described above, we examined the problem of tool use as one example of the broader phenomenon of learning about goals behind increasingly complex actions. We expect, however, that similar processes to those proposed in this

work likely play a role in recognizing the goals behind other actions as well.

As noted in other theories highlighting the potential role of comparisons between self and other, social interactions provide rich opportunities for alignment of actions and intentions. When infants engage in joint play, they often act on toys simultaneously with a social partner. Triadic interactions, in which two individuals (e.g., a mother and her child) share attention on an object, increase greatly during play at the end of the first year of life. These opportunities for shared attention allow the infant to physically align his or her attention on the same goal as a social partner (see Barresi & Moore, 1996). An important opportunity for comparison also occurs during collaborative activity. When social partners engage in two distinct actions in order to achieve the same goal, the collaborative partners align their two actions and this alignment could facilitate the extraction of the common intentional relation. That is, comparing one's own action and goal with one's collaborative partner could help an individual extract the goal of his or her social partner's action. In the current work, an adult social partner (i.e., the experimenter) scaffolded joint action by initiating the action and providing the infant with a toy for which it was assumed the infant would want to grasp. Through the development of more complex social and cognitive capacities, infants and children eventually become able to engage in more active collaborations (e.g., Meyer, Bekkering, & Paulus, Hunnius, 2010) that could provide rich opportunities for alignment and social learning. Joint play, joint attention, and collaboration are ubiquitous throughout early development and could jointly or independently provide rich opportunities for social learning through comparison. Differences in frequency and form of social interactions could also prove to be an interesting source of individual differences in action understanding within and across cultures (see Brune & Woodward, 2007; Gaskins & Paradise, 2010; Hofer, Hohenberger, Hauf, & Aschersleben, 2008).

The current findings provide new evidence that these kinds of opportunities for comparisons that are inherent in everyday social interactions play an important role in the development of social cognition. Further, they add to a growing literature suggesting an important role for comparison in cognitive learning during the first year (e.g., Oakes et al., 2009; Pruden et al., 2008; Wilcox et al., 2010). These findings also raise several questions concerning the extent to which comparison affects infants' action understanding. In these studies, we used tool use as an example of a novel action that infants at these ages did not yet understand, but we suspect that a similar process plays a role in discerning the goals behind increasingly complex actions. Further research is needed to evaluate the extent to which comparison supports infants' analysis of actions in general.

A related issue is whether comparison only supports inferences about human actions, or might also support analysis of any event in which one entity moves toward another, regardless of whether a human agent is involved (e.g., when animated objects carry out actions). It is of note that the action-goal infants learned about in this series of studies was a novel kind of *human* action. In each of the

studies, infants always saw an experimenter acting on the toy with a tool. It must be noted that older infants and adults can reason about the goals of non-human agents (e.g., Biro & Leslie, 2007; Gergely & Csibra, 2003). Whether they are able to extract the goals of actions performed by unfamiliar agents through analogy with familiar human actions or through a different mechanism is currently unknown and should be examined in future research.

Another question involves the nature of the goal information infants recovered from alignment training. The training involved socially coordinated actions, and it is not clear whether infants understood the experimenter's tool use actions in terms of the social goal of toy exchange or in terms of the experimenter's goal in grasping the toy. They could have learned that the goal of the game was to reach for the toy that the experimenter reached for, rather than having learned the individual goal of the experimenter's tool use action. In both cases, infants would have learned a goal rather than an associative response. The question is simply a matter of whether they learned a collaborative or an individual goal. A measure of action understanding that is external to the game (assessed through eyetracking or habituation paradigms like Woodward (1998), for example) is necessary in order to address this issue.

Finally, further explanation of why active engagement in physical alignment is more beneficial than observation of physical alignment is necessary. This finding is consistent with previous research (and theoretical proposals) indicating that, in the domain of social cognition, comparison between the self and other is initially more beneficial than the third-person perspective of comparison between two others. This is likely because the first person perspective provides information about the goals that drive actions that may not be available from observation alone (Barresi & Moore, 1996; Meltzoff, 2005; Moll & Tomasello, 2007; Moll et al., 2007). Even so, findings from other domains raise the possibility that children eventually become able to benefit from comparisons that are external to the self. For example, in the study by Moll and colleagues (2007) described above, although 14-month-olds did not learn about an experimenter's knowledge states from observing joint engagements, 18-month-old infants *were* able to learn from the observation of the same event. When and how infants gain the capacity to learn from observation in the domain of action understanding is currently unknown. Further research is needed to address each of these questions.

Beyond this, the actions being compared may not always need to be produced simultaneously, as in the examples in the current studies. It seems plausible that infants should eventually be able to compare actions that span time and/or space. Developmental work indicates that children get better at seeing analogies without support (e.g., without physical co-presence, perceptual similarity or labeling; Gentner, 1988) as they gain more experience within a particular domain. Even beyond childhood, individuals improve in their ability to make more abstract analogies with domain-specific experience and knowledge (e.g., Chi, Feltovich, & Glaser, 1981). It is likely that a similar developmental pattern exists in the social domain, but

once again, we do not yet know when and how this development occurs.

These questions aside, the current findings suggest a means by which infants could overcome initial limits on their action understanding. By engaging in comparison and analogical extension, infants may glean insights into the goals behind actions they have never seen or performed themselves. Critically, this mechanism could have a broad impact on infants' action knowledge because joint action is pervasive in everyday social life.

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References

Baillargeon, R., & Wang, S. (2002). Event categorization in infancy. *Trends in Cognitive Sciences, 6*, 85–93. doi:10.1016/S1364-6613(00)01836-2.

Barresi, J., & Moore, C. (1996). Intentional relations and social understanding. *Behavioral and Brain Sciences, 19*, 107–122. doi:10.1017/S0140525X00041790.

Biro, S., & Leslie, A. M. (2007). Infants' perception of goal-directed actions: Development through cue-based bootstrapping. *Developmental Science, 10*, 379–398. doi:10.1111/j.1467-7687.2006.00544.x.

Brune, C. W., & Woodward, A. L. (2007). Social cognition and social responsiveness in 10-month-old infants. *Journal of Cognition and Development, 8*, 133–158. doi:10.1080/15248370701202331.

Cannon, E., & Woodward, A. L. (March, 2010). Familiar actions trump "action-effects" in goal detection in the first year. *Paper presented at international conference on infant studies*. Baltimore, MD.

Chen, Z., Sanchez, R. P., & Campbell, T. (1997). From beyond to within their grasp: The rudiments of analogical problem solving in 10- and 13-month-olds. *Developmental Psychology, 33*, 790–801. doi:10.1037//0012-1649.33.5.790.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*, 121–152. doi:10.1207/s15516709cog0502_2.

Childers, J. B. (2008). The structural alignment and comparison of events in verb acquisition. In V. S. Sloutsky, B. C. Love, & K. McRae (Eds.), *Proceedings of the 30th annual cognitive science society* (pp. 681–686). Austin, TX: Cognitive Science Society.

Christie, S., & Gentner, D. (2010). Where hypotheses come from: Learning new relations by structural alignment. *Journal of Cognition and Development, 11*, 356–373. doi:10.1080/15248371003700015.

Gaskins, S., & Paradise, R. (2010). Learning through observation in daily life. In D. F. Lancy, J. Bock, & S. Gaskins (Eds.), *The anthropology of learning in childhood* (pp. 85–119). Lanham, MD: Alta-Mira Press.

Gentner, D. (1988). Metaphor as structure mapping: The relational shift. *Child Development, 59*, 47–59. doi:10.2307/1130388.

Gentner, D. (2003). Why we're so smart. In D. Gentner & S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and thought* (pp. 195–235). Cambridge, MA, USA: MIT Press.

Gentner, D., & Medina, J. (1998). Similarity and the development of rules. *Cognition, 65*, 263–297. doi:10.1016/S0010-0277(98)00002-X.

Gergely, G., & Csibra, G. (2003). Teleological reasoning in infancy: The naïve theory of rational action. *Trends in Cognitive Sciences, 7*, 287–292. doi:10.1016/S1364-6613(03)00128-1.

Hamlin, J. K., Hallinan, E. V., & Woodward, A. L. (2008). Do as I do: 7-Month-old infants selectively reproduce others' goals. *Developmental Science, 11*, 487–494. doi:10.1111/j.1467-7687.2008.00694.x.

Heineman-Pieper, J., & Woodward, A. L. (2003). Understanding infants' understanding of intentions: Two problems of interpretation. *Consciousness and Cognition, 12*, 770–772. doi:10.1016/j.concog.2003.08.007.

Hoehl, S., Parise, E., Palumbo, L., Reid, V. M., Handl, A., & Stirano, T. (2009). Looking at eye gaze processing and its neural correlates in infancy – Implications for social development and autism spectrum disorder. *Child Development, 80*, 968–985. doi:10.1111/j.1467-8624.2009.01311.x.

Hofer, T., Hauf, P., & Aschersleben, G. (2005). Infant's perception of goal-directed actions performed by a mechanical device. *Infant Behavior & Development, 28*, 466–480. doi:10.1016/j.infbeh.2005.04.002.

Hofer, T., Hohenberger, A., Hauf, P., & Aschersleben, G. (2008). The link between maternal interaction style and infant action understanding. *Infant Behavior & Development, 31*, 115–126. doi:10.1016/j.infbeh.2007.07.003.

Johnson, S. C., Shimizu, Y. A., & Ok, S. (2007). Actors and actions: The role of agent behavior in infants' attribution of goals. *Cognitive Development, 22*, 310–322. doi:10.1016/j.cogdev.2007.01.002.

Jovanovic, B., Király, I., Elsner, B., Gergely, G., Prinz, W., & Aschersleben, G. (2007). The role of effects for infants' perception of action goals. *Psychologia: An International Journal of Psychology in the Orient, Development of Social Cognition, 50*, 273–290. doi:10.2117/psysoc.2007.273.

Kotovsky, L., & Gentner, D. (1996). Comparison and categorization in the development of relational similarity. *Child Development, 67*, 2797–2822. doi:10.2307/1131753.

Lavelli, M., & Fogel, A. (2005). Developmental changes in the relationship between the infant's attention and emotion during early face-to-face communication: The 2-month transition. *Developmental Psychology, 41*, 265–280. doi:10.1037/0012-1649.41.1.265.

Loewenstein, J., & Gentner, D. (2001). Spatial mapping in preschoolers: Close comparisons facilitate far mappings. *Journal of Cognition and Development, 2*, 189–219. doi:10.1207/S15327647JCD0202_4.

Loewenstein, J., & Gentner, D. (2005). Relational language and the development of relational mapping. *Cognitive Psychology, 50*, 315–353. doi:10.1016/j.cogpsych.2004.09.004.

Luo, Y., & Baillargeon, R. (2005). Can a self-propelled box have a goal? Psychological reasoning in 5-month-old infants. *Psychological Science: A Journal of the American Psychological Society / APS, 16*, 601–608. doi:10.1111/j.1467-9280.2005.01582.x.

Luo, Y., & Johnson, S. C. (2009). Recognizing the role of perception in action at 6 months. *Developmental Science, 12*, 142–149. doi:10.1111/j.1467-7687.2008.00741.x.

Mahajan, N., & Woodward, A. L. (2009). Seven-month-old infants selectively reproduce the goals of animate but not inanimate agents. *Infancy, 14*, 667–669. doi:10.1080/15250000903265184.

Mangold, P. (1998). *Interact (computer software)*. Arnstorf, Germany: Mangold International.

Meltzoff, A. N. (1995). Understanding the intentions of others: Re-enactments of intended acts by 18-month-old children. *Developmental Psychology, 31*, 838–850. doi:10.1037/0012-1649.31.5.838.

Meltzoff, A. N. (2005). Imitation and other minds: The 'like me' hypothesis. In S. Hurley & N. Chater (Eds.). *Perspectives on imitation: From neuroscience to social science: Imitation, human development, and culture* (Vol. 2, pp. 55–77). Cambridge, MA, USA: MIT Press.

Meyer, M., Bekkering, H., Paulus, M., & Hunnius, S. (2010). Joint action coordination in 2 1/2- and 3-year-old children. *Frontiers in Human Neuroscience, 211*, 581–592. doi:10.3389/fnhum.2010.00220.

Moll, H., Carpenter, M., & Tomasello, M. (2007). Fourteen-month-olds know what others experience only in joint engagement. *Developmental Science, 10*, 826–835. doi:10.1111/j.1467-7687.2007.00615.x.

Moll, H., & Tomasello, M. (2007). How 14- and 18-month-olds know what others have experienced. *Developmental Psychology, 43*, 309–317. doi:10.1037/0012-1649.43.2.309.

Namy, L. L., & Gentner, D. (2002). Making a silk purse out of two sow's ears: Young children's use of comparison in category learning. *Journal of Experimental Psychology: General, 131*, 5–15. doi:10.1037//0096-3445.131.1.5.

Oakes, L. M., Kovack-Lesh, K. A., & Horst, J. S. (2009). Two are better than one: Comparison influences infants' visual recognition memory. *Journal of Experimental Child Psychology, 104*, 124–131. doi:10.1016/j.jecp. 2008.09.001.

Pruden, S. M., Hirsh-Pasek, K., Maguire, M. J., & Meyer, M. A. (2004). Foundations of verb learning: Infants form categories of path and manner in motion events. In A. Brugos, L. Micciulla, & C. E. Smith (Eds.), *Proceedings of the 28th annual Boston university conference on language development* (pp. 461–472). Somerville, MA: Cascadilla Press.

Pruden, S. M., Shallcross, W. L., Hirsh-Pasek, K., & Golinkoff, R. M. (2008). Foundations of verb learning: Comparison helps infants abstract event components. In H. Chan, H. Jacob, & E. Kapia (Eds.), *Proceedings of the 32nd annual Boston university conference on language development* (pp. 402–414). Somerville, MA: Cascadilla Press.

Sommerville, J. A., Hildebrand, E. A., & Crane, C. C. (2008). Experience matters: The impact of doing versus watching on infants' subsequent perception of tool-use events. *Developmental Psychology, 44*, 1249–1256. doi:10.1037/a0012296.

Sommerville, J. A., & Woodward, A. L. (2005). Pulling out the intentional structure of action: The relation between action processing and action production in infancy. *Cognition, 95*, 1–30. doi:10.1016/j.cognition.2003.12.004.

Sommerville, J. A., Woodward, A. L., & Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. *Cognition, 96*, B1–B11. doi:10.1016/j.cognition.2004.07.004.

Tomasello, M. (1999). *The cultural origins of human cognition*. Cambridge, MA, USA: Harvard University Press.

Tomasello, M., & Moll, H. (2010). The gap is social: Human shared intentionality and culture. In P. Kappeler & J. Silk (Eds.), *Mind the gap: Tracing the origins of human universals* (pp. 331–349). Berlin: Springer.

Wilcox, T., Smith, T., & Woods, R. (2010). Priming infants to use pattern information in an object individuation task: The role of comparison. *Developmental Psychology, 47*, 886–897. doi:10.1037/a0021792.

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition, 69*, 1–34. doi:10.1016/S0010-0277(98)00058-4.

Woodward, A. L., Sommerville, J. A., Gerson, S., Henderson, A. M. E., & Buresh, J. (2009). The emergence of intention attribution in infancy. In B. H. Ross (Ed.). *The psychology of learning and motivation* (Vol. 51, pp. 187–222). San Diego, CA, USA: Elsevier Academic Press.