Title: The Joint Role of Trained, Untrained, and Observed
Actions at the Origins of Goal Recognition

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- Active training uniquely informs action understanding at 3 months
- Observational training does not provide the same benefit
- Spontaneous activity interacts with observational training to influence action understanding
- Individual differences in spontaneous activity are not beneficial on their own

Abstract

Recent findings across a variety of domains reveal the benefits of self-produced experience on object exploration, object knowledge, attention, and action perception. The influence of active experience may be particularly important in infancy, when motor development is undergoing great changes. Despite the importance of self-produced experience, we know that infants and young children are eventually able to gain knowledge through purely observational experience. In the current work, three-month-old infants were given experience with object-directed actions in one of three forms and their recognition of the goal of grasping actions was then assessed in a habituation paradigm. All infants were given the chance to manually interact with the toys without assistance (a difficult task for most three-month-olds). Two of the three groups were then given additional experience with object-directed actions, either through active training (in which Velcro mittens helped infants act more efficiently) or observational training. Findings support the conclusion that self-produced experience is uniquely informative for action perception and suggest that individual differences in spontaneous motor activity may interact with observational experience to inform action perception early in life.

The Joint Role of Trained, Untrained, and Observed Actions at the Origins of Goal Recognition

"Children learn as they play. Most importantly, children learn how to learn."

– O. Fred Donaldson

"Observation opens windows of knowledge around us."

– Sukan Ratnaker

Since Piaget (1954), the active role a child plays in creating experiences for him- or herself that drive development has been a topic of intense study in a variety of domains. This kind of experience has been hypothesized to be particularly critical in infancy, when the nature of self-produced action is undergoing marked developmental changes. For example, researchers have discovered links between the development of locomotion and a number of cognitive abilities, including emotional understanding (e.g., Campos, Bertenthal, & Kermoian, 1992), spatial memory (Bertenthal, Campos, & Barrett, 1984; Campos, Anderson, Barbu-Roth, Hubbard, Hertenstein, & Witherington, 2000), and joint attention (Karasik, Tamis-Lamonda, & Adolph, 2011). Further, engagement in manual actions has been associated with developments in causal understanding (Rakison & Krogh, 2011), and object perception, and well as developments in object exploration (Libertus & Needham, 2010; Lobo & Galloway, 2013; Mohring & Frick, 2013; Oakes & Baumgartner, 2012).

In recent years, a number of findings have shown links between self-produced actions and the perception of others' actions, the object on which they are acting, and the relation between these during infancy. For example, Cannon and colleagues (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2011) found that the propensity of 12-month-old infants to perform containment actions (i.e., putting objects into a bucket) was related to their visual anticipation of the goal of this action when observed during an eyetracking experiment (i.e., looking to a bucket before an actor placed an object inside). Similarly, Gredebäck and Kochukhova (2010) found that 25-month-old toddlers' puzzle-solving ability was related to their visual prediction of another's actions in putting together a puzzle. Other work indicates action-specific links between the stage of motor development and perception of others' action goals (e.g., shared attention and pointing: Brune & Woodward, 2007; means-end actions: Sommerville & Woodward, 2005; Sommerville, Hildebrand & Crane, 2008).

The natural development of particular motor skills provides an ideal case in which to study relations between motor learning and action perception, as described in the correlational studies above. In order to determine the causal direction of these links, however, intervention studies are necessary. Before infants are able to produce particular motor acts on their own, they can be trained to produce these actions and the effect of these experimentally-induced experiences can be assessed in relation to action perception.

For example, three-month-old infants are not yet proficient at producing efficient object-directed reaches wherein they direct their actions toward an object and move or retrieve that object. Giving infants experience using Velcro mittens to play with Velcro covered toys at this age allows them to produce more efficient, object-directed reaches (see Needham, Barrett, & Peterman, 2002) and affects infants' perception of people, events, and the relations between an actor and an object on which he or she acts. Active training leads three- and four-month-old infants to attend more to faces (i.e., social agents, Libertus & Needham, 2010), perceive causality in motion events (Rakison & Krogh, 2012), and recognize the relation between an actor and her goal when she reaches for a particular object (Sommerville, Woodward, & Needham, 2005). Control conditions in each of these studies showed that infants this age responded differently to the agents, events, and actions when they did not receive active training.

Some researchers have suggested that developments in action perception and action production are linked by shared neuro-cognitive representations, sometimes called “mirror systems.” This system is responsive both during the production and perception of motorically familiar goal-directed actions (Decety & Sommerville, 2003; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Gallese & Goldman, 1998; Lepage & Théoret, 2006). Though the majority of work concerning the mirror system in humans has been conducted with adults (e.g., Grezes & Decety, 2001; Rizzolatti & Craighero, 2004), increasing neurophysiological evidence indicates that this system may be in place in infancy, in that neural responses associated with action production are observed when infants view (or perceive) others’ goal-directed actions or the effects of those actions (Marshall & Meltzoff, 2011; Paulus, Hunnius, van Elk, & Bekkering, 2012; Saby, Marshall, & Meltzoff, 2012; Shimada & Hiraki, 2006; Southgate, Johnson, Karoui, & Csibra, 2010; Southgate, Johnson, Osborne, & Csibra, 2009;). For example, Paulus and colleagues (Paulus et al., 2012) found that 8-month-old infants who learned a novel association between a sound and a familiar action (i.e., heard a sound when they shook an object) later showed motor activation when listening to this sound (without any visual input) and not to another sound (to which they were familiarized without the presence of an action).

Together, these findings indicate that the experience of producing actions influences early developments in action perception. However, these findings leave open questions concerning the aspects of the active experience that drive these effects. In particular, when infants engage in actions they also create for themselves observational experience watching those actions. It is not clear whether action production yields different kinds of developmental outcomes than does observational experience. Observational experience could shape action perception because it provides informative statistical evidence (e.g., when a hand touches an object, the object often moves) or because it may activate the mirror system on its own, with no need for the infant to engage in the action per se. In fact, in a follow-up to the above study conducted by Paulus and colleagues (2012), it was found that observation of actions and their effects was sufficient to lead to motor activation in response to the effect. Other work, however, suggests that self-produced experience is influential, above and beyond the effects of observational experience.

Correlational work by van Elk and colleagues (van Elk, van Schie, Hunnius, & Bekkering, 2008) provides indirect evidence that active experience is unique in its modulation of motor activity in infants, as measured with electroencephalography (EEG). In this work, van Elk et al. measured brain activity over motor regions while 15-month-old infants watched videos of other children walking and crawling. Infants' motor systems (as measured through suppression of mu rhythm over motor areas; see Marshall & Meltzoff, 2011; Vanderwert, Fox, & Ferrari, 2012 for reviews) were more responsive when observing videos of infants crawling than walking. The authors suggested this was because crawling was an action with which infants at this age had more active experience. In support of this argument, the variation between infants in amount of experience walking (as measured in months since beginning to walk; independent of age) was related to the amount of motor activity detected while infants watched the videos of walking children. Young infants are exposed to many more individuals walking than crawling in their environment, but this observation of walking does not seem to drive motor activity in the brain, as the extent of motor activity was related to the amount of experience *producing* this action themselves. This suggests that self-produced experience uniquely modulated motor activity in the brain when later observing similar actions in this study. This is consistent with adult research on the mirror system suggesting that the system is particularly responsive to actions within one's motor repertoire and that motor expertise modulates motor activity in response to observed actions (e.g., Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005).

As noted before, correlational evidence alone does not provide direct information about the causal factors that give rise to correlated patterns. Several recent studies have addressed the differences between active and observational experience on perception of agents, objects, and actions through intervention studies. Libertus and Needham (2011) gave three-month-old infants experience producing object-directed actions with Velcro mittens *or* experience watching these actions produced by a parent. After passive training, infants were more likely to attend to the experimenter (agent) while watching her act, whereas infants who received active training were more likely to look back and forth between the toy on which she acted and the environment (e.g., the experimenter, the parent). As noted by the authors, infants in the active condition demonstrated more "interest in actions and interactions between object and environment in a live context [and that] this behavior may facilitate learning about the goals and actions of others" (p. 2756).

In a study by Sommerville and colleagues (Sommerville et al., 2008), ten-month-old infants were either trained how to produce tool-use actions or observed tool-use training. At this age, infants who received active training later perceived an actor's tool-use action as directed toward a goal, whereas infants who observed training did not. Similarly, Gerson and Woodward (in press) investigated the unique effects of active experience, relative to observational experience, at the origins of action production and perception. In a follow-up to Sommerville and colleagues' (2005) study in which three-month-old infants were trained to produce object-directed actions with Velcro mittens, Gerson and Woodward trained one group of three-month-old infants with mittens and allowed a second group of infants to observe mittened actions on the same toys. In concordance with the findings of Sommerville et al. (2008), infants who produced object-directed actions, but not those who observed these actions, later perceived the goal of an actor's reaching action. In both studies by Sommerville and colleagues (2005, 2008), individual differences in the amount of experience gained during active training was related to differences in the extent of goal recognition. Interestingly, when infants are at the brink of being able to perform these actions, as they were in these studies, brief active training influenced their perception of others' actions, but similar amounts of observational experience (i.e., watching object-directed actions with a mitten or watching tool-use training) did not have the same effect.

These studies suggest that active experience is more powerful than observational experience in shaping infants' action perception. They leave unanswered, however, why this is the case and to what extent the presence and importance of observational learning at other points in development (e.g., Paulus et al., in press) can be reconciled with the unique early benefits of self-produced experience. One possibility is that observational experience produces similar, but weaker effects as active experience. In the previous study by Gerson and Woodward (in press), in which three-month-old infants received either active or observational experience with object-directed actions, infants in the observational condition received similar amounts of experience viewing object-directed actions as infants in the active condition produced. Although no group effect of observational experience emerged within this range of activity (between 10 and 180 seconds of object-directed activity), individual differences in observational experience received was not discussed. In the Sommerville et al., 2008 training study, all infants in the observational condition received matched amounts of experience, making it impossible to examine individual differences in amounts of observational experience (but see Sommerville, Blumenthal, Venema, & Sage, 2011). In both the Sommerville et al. 2005 and 2008 studies, however, individual differences in *active* training related to infants' action perception. Assessing individual differences in observational experience can shed light on whether active and observational experience are qualitatively or quantitatively different.

A second factor left unexamined in previous studies is the potential effect of individual differences in untrained, spontaneous motor development or motor activity on learning from observation. The ages of infants in the above-mentioned training studies were chosen so as to take advantage of time points in development at which the majority of infants were at the cusp of being able to produce the trained actions. Because of this, variability in unmittened activity (i.e., prior to training) could provide important information about individual differences in infants' motor development. Further, differences in infants' motor competence could mediate learning from either active or observational experience. Although Sommerville et al. (2005) found no direct effects of untrained actions on infants' action understanding when infants were also given mittened training, it is possible that unmittened activity is meaningful on its own or in conjunction with observational experience.

In the current study, we addressed these gaps in the literature by closely examining the roles of individual differences in observational experience and unmittened actions produced. We replicated the active and observational conditions from Gerson and Woodward (in press) by creating a yoked paradigm in which infants in the observational condition received a similar range of experience as infants in the active condition, allowing us to examine the role of individual differences in observational experience. In order to evaluate the possible role of individual differences in unmittened activity, we supplemented these conditions with a control condition in which another group of 3-month-old infants were given the opportunity to engage in spontaneous, untrained activity with the same toys but did not receive active or observational training. In this way, we provided a test of the unique benefits of active experience and also examined, in greater detail, whether similar individual differences existed in the observational condition as in the control condition.

Method

Participants

Seventy-two full-term (at least 37 weeks gestation) three-and-a-half-month-old infants were assigned to one of three conditions: active (*n* = 24; 10 males; *M* age = 3;14), observational (*n* = 24; 11 males; *M* age = 3;15), or control (*n* = 24; 12 males; *M* age = 3;13). Infants were recruited from the Washington, DC metropolitan area through mailings and advertisements. The sample of infants was 17% African-American, 3% Asian, 46% Caucasian, 15% Hispanic, 8% multiracial, and 11% unreported. In order to be included in the final sample, infants had to complete the training phase and then complete at least two test trials in the looking time procedure. An additional 14 infants in the active condition, 13 in the observational condition, and 11 in the control condition began testing but were not included in the final sample because they were unable to complete the procedure due to distress. An additional four infants failed to engage in training and were not included, seven infants were not included due to equipment or procedure error, and 16 infants were excluded due to low inter-observer agreement (see coding section below for details).

Procedure

Pre-training unmittened actions. All infants were first given the opportunity to act on two toys with their bare hands while seated on a parent’s lap facing a small table. Parents were asked to support their infants as they sat at the table, but not to interfere with their actions. The experimenter sat to the side of the table and placed a toy bear (12.7 cm in length) and a toy ball (5.1 cm in diameter), both covered in Velcro, approximately 8 centimeters apart in the center of the table. During the 3-minute session (and in all proceeding sessions), the experimenter ensured the infant's hands were on the table and drew the infant's attention to the toys by tapping or moving the toys periodically if the infant was not attending. After this session , infants in the control condition were immediately tested in the habituation paradigm. Infants in the active and observational conditions underwent training, as described below.

Active mittens training. In the active condition, the experimenter then fitted the infant with Velcro mittens (see Figure 1a). When the infant apprehended a toy, the experimenter allowed the infant to maintain manual contact with the toy for as long as he continued to look at the toy while touching it. When the infant broke visual contact, the experimenter detached the toy, placed it back on the table and drew the infant's attention back to the toys. Infants' coordinated visual and manual activity on the toy mainly involved watching a toy while moving it back and forth across the table top with the mitten. This training lasted three minutes.

Observational mittens training. Infants in the observational condition were yoked to active infants of the same gender and age. The amount of time each active infant engaged in object-directed activity on each toy (see coding section below for details) was used to generate a training script for the yoked infant in the observational condition. This measure was used as the basis of yoking because it has been found to relate to goal-recognition in previous studies above and beyond other factors such as number of contacts made with toys (Sommerville et al., 2005). During the training session, one experimenter wore a Velcro mitten and placed both toys a few centimeters beyond the infant's armspan but within view (see Figure 1b). In order to match the type of activity produced by infants in the active condition, the experimenter reached toward, contacted, and moved each toy around on the table (using a Velcro mitten) within the infant's view in similar patterns to those engaged in by active infants (moving toy back and forth across the table and occasionally lifting it). The experimenter moved each of the toys (bear, ball, or both simultaneously) for approximately the amount of time the infant's yoked partner had played with each toy. The experimenter drew the infant's attention to the toy if he was not attending. We ensured that infants watched the experimenter's actions on the toys for the scripted amount of time (with the use of two additional experimenters watching through a window, using a stopwatch to measure the timing of infant's attention to the toys). Thus, the scripted time was the amount of time the infant observed the experimenter's actions (erring on the side of more experience in the observational condition), not the amount of time the experimenter acted on the toys.

Habituation phase. All infants were then tested in a habituation procedure modeled after Sommerville et al.'s study (2005) and designed to assess infants' encoding of reaching actions as goal-directed. Infants sat on a parent's lap approximately 71 cm from a stage holding a bigger version of the bear (25.4 cm in length) and ball (10.2 cm in diameter), each on 5.1 cm high pedestals, approximately 35 cm apart. Parents were asked not to talk or gesture toward the stage, and they were asked to look down at the infant, rather than the stage, during test trials. The camera view of the infant was sent to a coder in another room who judged whether the infant was watching the event. All trials were infant-controlled and ended when infants looked away for two consecutive seconds.

During habituation trials, the presenter sat to the side of the stage and reached through the side curtain, wearing a Velcro mitten, to grasp one of two toys (see Figure 2a). She held this position until the trial ended. This habituation procedure exactly matched the procedure in Sommerville et al. (2005) and Gerson and Woodward (in press). Habituation trials were repeated until the length of the last three trials was less than half the length of the first three trials or until 14 trials had occurred.

After habituation, the presenter switched the placement of the toys on the stage while the curtain was raised (so the infant did not see). In a familiarization trial, the infant viewed the toys in their new positions without any action. Infants were then shown six test trials alternating between new-goal and old-goal events (see Figure 2bc). On new-goal trials, the presenter reached to the same side of the stage as during habituation, this time grasping the other toy. On old-goal trials, she reached to the other side of the stage in order to grasp the same toy as in habituation. In this paradigm, a novelty response (longer looking) to new-goal trials relative to old-goal trials is taken as evidence that infants recognize the goal structure of the action (Sommerville et al., 2005; Woodward, 1998, 1999). As in habituation, once the presenter grasped the toy, she held her position until the end of the trial. The toy grasped in habituation, the side of the habituation reach, and the order of test trials were counterbalanced across infants and matched across yoked infants in the active and observational training conditions.

Coding of habituation paradigm responses. Infants' looking times were measured using a coding program that calculated the habituation criterion (Casstevens, 2007; Pinto, 1994). Coders could not see the experimental event and were unaware of the order of test trials. To assess reliability, a second, independent coder coded the test trials of all of the sessions from the video record. The two coders' judgments of trial length were strongly correlated ($r \geq .94$ in all conditions). As a more stringent test, we assessed the proportion of test trials for which the online and reliability coders identified the same endpoint. Since trials ended when infants had looked away from the event for two seconds or more, observers were counted as agreeing if they identified the same shift in the infants' gaze away from the event as ending the trial. Coders agreed on the end of the test trials 89% of the time across the three conditions. Disagreements were randomly distributed with respect to the hypothesis (Fisher's exact test, *ns*).

Coding of infants' actions. Infants' untrained (i.e., unmittened; for all conditions) and mittened actions (in the active condition) were coded for the amount of time each infant spent looking at and touching each of the objects using a digital coding program (Mangold, 1998). Of interest was the extent to which infants engaged in coordinated object-directed actions on the toys. To operationalize this, as in Sommerville et al. (2005; see also Gerson & Woodward, in press), for both unmittened pre-training and mittened training, we coded the amount of time each infant spent simultaneously looking at and touching each toy. To obtain a parallel measure of infants' experience in the observational condition, we coded their visual attention to the experimenter's actions, that is, the total amount of time they watched as the experimenter's mittened hand acted on the toys. A second independent coder coded 25% of the sessions (both unmittened pre-training and mittened training) in all conditions. The two coders' judgments of object-directed actions were strongly correlated (r's $\geq .91$).

Results

We conducted three sets of analyses. The first examined infants' engagement in and observation of actions during the pre-training and training phases, the second examined infants' responses to the visual habituation and test events, and the third examined the relations between infants' training experiences and their visual habituation responses.

Training Experiences

We first analyzed infants' actions during the training procedure. A one-way Analysis of Variance (ANOVA) verified that infants in the three conditions did not differ in their unmittened object-directed activity during the pre-training phase ($F(2,69) = 1.02$, $p = .36$; mean activity in seconds in the active, observational, and control conditions, respectively: 16.34s [*SEM* = 4.37], 9.35s [*SEM* = 2.72], 14.32s [*SEM* = 3.37]). Thus, the three groups of infants were comparable in their initial ability to produce object-directed actions prior to any mittens training.

We next considered infants' level of experience during training. Infants in the active condition and their yoked partners in the observational condition received similar levels of exposure to object-directed activity during training, as indicated by a strong correlation between seconds producing and observing object-directed activity across yoked pairs ($r = .86$). Infants in the observational and active condition did not differ in the amount of object-directed activity they experienced during training ($t(46) = 1.29$, $p = .20$; means seconds in the active and observational condition, respectively: 66.89s [*SEM* = 5.00] and 76.27s [*SEM* = 5.27]). Infants in both conditions gained more visual experience with object-directed actions during the training phase than during the unmittened pre-training phase (*t*s > 5.65; *p*s < .001; Cohen's *d*s > 2.54).

Visual Habituation Responses

Next, we considered infants' responses to the habituation and test events. Because of skew in looking times (Kolmogorov-Smirnov, *p*s < .05), looking time data were log-transformed before being entered into analyses. In order to account for the yoking (of counterbalancing factors and/or mittens experience) across the three conditions, matched infants were analyzed with condition as a repeated measure. First, we evaluated whether infants in the three conditions demonstrated similar levels of attention to the habituation events. The sum of looking times to the first and last three trials of habituation were log-transformed and entered into analyses as dependent measures. A repeated measures analysis of variance (ANOVA) with habituation trial (sum of the log of the first three and sum of the log of the last three habituation trials) and condition (active, observational, and control; yoked partners matched) as the repeated factors indicated that infants' looking times declined throughout habituation trials across groups ($F(1, 23) = 240.18$, $p < .001$; $\eta_p^2 = .91$). The lack of main effect of condition ($F(1, 22) = .16$, $p = .85$, $\eta_p^2 = .015$) indicates that overall attention was similar across conditions, and the lack of an interaction between trial and condition ($F(1, 22) = .15$, $p = .86$, $\eta_p^2 = .014$) suggests that habituation rates were similar across conditions. Thus, infants in all conditions demonstrated similar levels of attention prior to test trials.

We then evaluated whether infants in the three conditions differed in their responses to the test (new-goal and old-goal). Infants' average looking times across the three test-trials of each goal-type event (new-goal versus old-goal) were log-transformed. Preliminary analyses revealed no effects of age, sex, goal in habituation (bear or ball) or test trial order (new-goal or old-goal first). Therefore, subsequent analyses collapsed across these factors. An effect of side of reach during habituation (near versus far side of stage) was found and thus remained in further analyses. A repeated measures ANOVA with Condition (active, observational, or control; yoked partners treated as repeated measures) and test-trial Goal-Type (log-transformation of average seconds looking to new-goal vs. old-goal trials) as repeated factors and side of Reach during habituation as a between subjects factor revealed no main effect of Goal-Type ($F(1,22) = .037$, $p = .85$) or Condition ($F(1,21) = .36$, $p = .71$), interaction between Condition and Reach ($F(1,21) = .68$, $p = .104$), or three-way interaction between Goal-Type, Condition, and Reach ($F(1,21) = 2.53$, $p = .52$). A significant interaction between Goal-Type and Reach ($F(1,22) = 4.72$, $p = .041$, $\eta_p^2 = .18$ and, importantly, a Goal-Type X Condition interaction ($F(1, 21) = 4.33$, $p = .027$; η_p^2

= .29) emerged. A priori pairwise comparisons of estimated marginal means (see Figure 3 for raw means and standard errors) indicated that infants looked longer to new-goal than old-goal trials in the active condition (*mean difference* = .30, *p* = .034, Cohen's *d* = .46) and not in the observational (*mean difference* = -.20, *p* = .27, Cohen's *d* = .23) or control condition (*mean difference* = -.17, *p* = .33, Cohen's *d* = .20). Pairwise comparisons of the estimated marginal means revealed no significant effects regarding the Reach X Goal-Type interaction (*mean differences* < .26, *p*s > .10).

Non-parametric analyses confirmed these results. The Friedman non-parametric test of related samples was conducted to examine whether relative attention to new-goal test-trials was different between the three conditions using a non-parametric measure. For this test, the dependent measure was average looking-time to new-goal trials divided by the sum of looking-times across all test-trials. This analysis revealed that the three conditions significantly differed from one another in preferential attention to new-goal test-trials, $\chi^2(2) = 9.00$, $p = .011$. Wilcoxon Signed Rank Tests of new-goal and old-goal looking times within each condition indicated that infants in the active condition demonstrated a significant preference for new-goal trials (*Z* = -2.00, *p* = .046), whereas infants in the observational (*Z* = -.69, *p* = .49) and control (*Z* = -1.03, *p* = .30) conditions did not significantly differ across test-trial goal-types.

Relations Between Training Experiences and Looking Time Responses

Finally, we examined relations between individual variation in infants' training experiences and their subsequent looking time responses. As in previous studies assessing individual differences in goal recognition (e.g., Sommerville et al., 2005), we used a measure of relative preference for the new-goal test-trial in the first pair of test trials. Due to the above-mentioned skew in looking times, we created a proportion score (rather than a difference score) of relative new-goal preference: (first new-goal looking time)/(first new-goal + first old-goal looking times). This score (henceforth referred to as *new-goal preference*) was then used as a dependent variable in a series of regression analyses.

In the active and observational conditions, *mittens experience* was defined as the amount of time (in seconds) that infants engaged in coordinated manual and visual contact on the objects while wearing the mittens in the active condition and the amount of time they attended to the experimenter's mittened actions on the objects in the observational condition. In order to assess the effect of individual differences in mittens experience on new-goal preference, a regression with new-goal preference as the dependent variable was run for each condition. Side of reach during habituation trials and order of test-trials (new-goal or old-goal test-trial first) were included as control variables. Mittens experience was centered before being entered into the analysis in order to examine any possible interactions (as suggested by Cohen, Cohen, West, & Aiken, 2003; see also Hayes & Matthes, 2009). When no interaction between mittened experience and the control variables were found (as assessed via Hayes and Matthes' (2009) PROCESS SPSS macro), follow-up analyses examined models consisting only of potential main effects.

The analyses of mittened activity in the active condition revealed both a main effect of mittened activity ($B = .0064$, $p = .041$) and a significant interaction between side of reach and mittened activity ($B = .017$, $p = .0095$). The inclusion of the interaction in this model led to a significant increase in R^2 ($\Delta R^2 = .30$, $p = .0095$). Examination of this interaction revealed that the effect of mittened activity was stronger for infants who saw the far reach during habituation trials, $B = .015$, $p = .014$, relative to infants who saw the near reaches, $B = -.0023$, $p = .26$; see Figure 4a). In the observational condition, there was no interaction between side of reach and amount of mittened activity (*p* = .72) or main effects of mittened activity or reach (*p*s > .31). Thus, amount of training with mittens played a role in the active condition but not in the observational condition.

In a final set of analyses, we evaluated whether infants' actions during the unmittened pre-training phase related to their subsequent responses in the habituation paradigm. Untrained activity was a measure of each infant's coordinated manual and visual contact with the objects during the period in which they interacted with them with their bare hands (prior to training). Due to skew in the amount of untrained object-directed activity infants produced (Kolmogorov-Smirnov, *p* < .05) and the inability to log-transform due to approximately four infants per condition with zero values for unmittened activity, we created an untrained activity rank score for each infant within each condition. The untrained rank score was simply an ordinal ranking of infants within each condition based on the amount of unmittened activity produced. The unmittened rank score was centered (in order to examine the interaction, as suggested by Cohen & Cohen, 2002, p. 203; see also Hayes & Matthes, 2009) and entered as a covariates in a regression that included side of reach and test-trial order.

In the active condition, no significant interaction between reach and unmittened activity was found (*p* = .97), and a follow-up generalized linear model (GLZM) regression without the interaction factor failed to reveal any significant main effects (*p*s > .34). In the observational condition, there was no significant interaction between side of reach and unmittened pre-training activity (*p* = .30). A follow up GLZM revealed a main effect of unmittened activity ($\chi^2(1) = 4.59$, *p* = .032; see Figure 4b) and no main effect of side of reach (*p* = .44). In the control condition, there was no interaction between unmittened activity and side of reach (*p* = .30) and followup analyses revealed no main effects (*p*s > .23; see Figure 4c). In summary, unmittened experience played no role in the active and control conditions but was a significant predictor of new-goal preference in the observational condition.

Discussion

At a group level, the current findings add to the growing body of evidence that self-produced actions support infants' developing ability to perceive meaningful structure in others' actions. The current findings replicate those of Sommerville and colleagues (2005) and Gerson and Woodward (in press) in showing that infants who engaged in object-directed activity with Velcro mittens subsequently show a pattern of selective attention to goal-change events that indicates sensitivity to the relational goal structure of another person's grasping actions. Infants who underwent active training looked reliably longer on new-goal than old-goal trials. Further, the current findings provide evidence that these effects did not emerge, at the group level, in infants who had the opportunity to act on toys without mittens (control condition) and/or to observe mittened actions (observational condition). These findings are consistent with, but do not provide direct evidence for, a proposed mirror system in infants.

These group-level differences cannot be accounted for by an effect of differential amounts of attention to the toys in the active and observational conditions. The way in which scripts were yoked in the observational condition ensured that infants in this condition viewed the toys being moved for equal or more time than infants in the active condition. Further, the habituation paradigm measured recognition of the *relation* between an agent and an object, so attention to objects could not have driven infants’ responses.

Although infants in the active condition gained multimodal experience that contained proprioceptive feedback when the experimenter removed the toy from the infant’s mitten when he or she was not attending, it is unclear how this could have driven the observed differences in infants’ looking time responses. In the active condition, the toy was pulled off the mitten when infants were inattentive. In the observational condition, the experimenter tapped on the table near the toys when the infant was inattentive. Both of these contingent responses could have played similar roles in drawing infants’ attention to the toys. Importantly, other kinds of contingency cues gained through proprioceptive feedback are inherent in active relative to observational experience in the real world. That is, one important difference between active and observational experience may be that one can create contingencies between one’s own visual and motor movements that are not possible when the motor movements are created by another individual. This enhances the ecological validity of our study but leaves open questions concerning which aspects of active experience are particularly beneficial for gaining understanding about others’ intentional actions.

Our study went beyond prior findings in exploring the possibility that observational experience renders a similar, though weaker, effect on infants action perception by investigating relations between the degree of experience and the strength of infants' responses to others' action goals. That is, we asked whether those infants with higher 'doses' of active or observational experience showed stronger goal selective responses on test trials. We found that infants in the active condition showed a positive relation between their own level of engagement in object-directed actions during mittens training and their relative preference on new goal, versus old goal trials, as was reported by Sommerville and colleagues (2005). Critically, we found no relation between observation of mittened actions and new-goal preference. The design of this study suggests that this lack of relation between the observation of mittened actions and new-goal preference may be informative. Given the yoked design, infants in the active and observational conditions saw a similar amount and range of mittened actions (active: *SEM* = 5.00;

observational: *SEM* = 5.27). Further, the degree of variation in new-goal preference scores was similar across all three conditions (active: *SEM* = .048; observational: *SEM* = .053; control: *SEM* = .052). We thus had equal opportunity to observe a correlation across conditions, but no relation emerged between mittened actions and new-goal preference in the observational condition.

Although the findings did not reveal a direct relation between observational experience and infants' responses to test events, they did reveal effects of infants' prior experiences. Specifically, there was a positive relation between infants' level of engagement in unmittened object-directed actions *prior* to training and their new-goal preference in the observational condition. This suggests that ongoing motor development or spontaneously occurring motor activity supports infants' analysis of others' actions. Additionally, this supports the above suggestion that variability in looking times responses in the observational condition was sufficient for a significant correlation to emerge.

Because unmittened activity was measured immediately prior to the habituation procedure, it is unclear whether variability in untrained activity was a function of infants' differing capabilities prior to entering the laboratory, whether engaging in this activity primed infants' responses in the moment, or whether some combination of pre-existing abilities and experience in the laboratory influenced infants' responses. Further studies are needed, which measure infants' capacity to perform object-directed activity without mittens outside of the session, in order to resolve this issue.

The relation between spontaneous object-directed actions (during unmittened activity) and new-goal preference was not found in our active condition or in the previous Sommerville et al. (2005) study. This could be because (as seen in the lack of correlation between unmittened and mittened activity) the mittens actually interfered with natural grasping actions for infants who were more adept at grasping on their own, making the mittens experience less helpful for more motorically advanced infants. In the current work, we created a control condition in which infants had neither active or observational training with mittens. We assessed the effects of these infants' unmittened activity prior to participation in the looking-time paradigm on new-goal preference. In contrast to the effect of unmittened actions in the observational condition, unmittened actions independent of any training, were unrelated to new-goal preference. This relation was null despite similar amounts of variability in new-goal preference between the control condition and the observational condition, in which this relation was significant. One difference between the control and observational conditions is that the control infants immediately underwent the habituation paradigm following the unmittened session, whereas the observational infants had between one and three minutes to acclimate to the laboratory setting before undergoing the habituation paradigm. This is unlikely, however, to account for differences as the length of time between the unmittened session and the beginning of the habituation session was unrelated to looking times in the observational condition.

Taken together, these findings indicate that experience producing actions without mittens training (i.e., in spontaneous activity) contributes to action perception, but only given the chance to observe mittened actions. This implies that observation of the mittened actions, though not effective at a group level, proved a critical experience for infants to build upon representations from their own, untrained actions. That is, our findings suggest that observational experience may have interacted with infants' unmittened experience in affecting infants' subsequent responses to the habituation events. This finding has not been explored or discussed previously and could shed light on how infants begin to transfer learning from active experience to observational experience.

This pattern of findings raises the question of the mechanism through which unmittened activity interacted with observational experience to influence action perception. One possibility is that infants compared their own unmittened actions with the passively observed mittened actions, and this comparison provided them with information relevant for understanding the subsequent habituation events. Research on cognitive learning in other domains suggests a mechanism by which this process could have occurred in the observational condition. Specifically, comparison can allow learners to detect relational similarities between two exemplars. When a familiar exemplar is compared to a novel one, this process can allow learners to discern relational structure in the novel exemplar, via a tacit analogy between the familiar and novel exemplars (Gentner, 1988, 2003; Gentner & Medina, 1998). Research with children and adults has demonstrated that analogical comparison supports learning about relational structure in several cognitive domains including language, categorization, mathematical reasoning, and problem-solving (Chen, Sanchez, & Campbell, 1997; Childers, 2008; Richland & McDonough, 2010; Gentner, 1988, 2003; Gentner & Medina, 1998; Rittle-Johnson & Star, 2007). The idea that analogical comparison might play a role in infants' detection of intentional relations was proposed by Gerson and Woodward (2010; see also Barresi & Moore, 1996; Tomasello, 1999) and has recently been supported by empirical work indicating that infants as young as seven months can generalize goal recognition from familiar to novel goal-directed actions through comparison (Gerson & Woodward, 2012; in press). In this work, experience comparing motorically familiar and unfamiliar actions that have a common goal allowed infants to understand the goal structure of the unfamiliar action, even though they never produced the unfamiliar action themselves. Whether this process is also possible in younger infants has yet to be directly tested (but see Ferry, Hespos, & Waxman, 2010; Ferry, Hespos, & Gentner, under review).

In order to use comparison to expand upon motorically familiar actions, an initial kernel of action understanding must first be in place. Without a goal-relation to which one action can be tied, it would be impossible to transfer knowledge about a goal to another action. The fact that infants' new-goal preference was influenced by their unmittened object-directed activity in the observational condition (but not control condition) is in line with this perspective. One explanation for the individual differences found in the observational condition in this study is that infants with a sufficient base of active experience (as indicated by the amount of unmittened activity produced) could then relate this familiar action (i.e., grasping a toy during untrained activity) to the novel action (e.g., observing someone grasp a toy while wearing a mitten) and by doing so come to understand the goal structure of the observed actions. This would also explain why there was no relation between unmittened activity and new-goal preference for infants in the control condition. In this condition, infants had no easily accessible way to compare their actions on the toys with the mittened actions. Thus, although more motorically advanced, infants in this condition had no way to "carry" their motor knowledge to a new context (i.e., the mittened actions).

If this hypothesis is correct, then as infants gain motor expertise, they should be more able to generate analogical comparisons when viewing novel actions. Consistent with this possibility, research examining the effects of observational learning on action perception in infancy suggests that the ability to learn how to perform novel actions through observation improves throughout the first two years of life (e.g., Fattori et al., 2000). Similarly, research by Moll and colleagues (Moll, Carpenter, & Tomasello, 2007; Moll & Tomasello, 2007) indicates that infants learned about others’ knowledge states from participation in joint engagement (at 14 months) before they were able to extract this same information from observing social partners jointly engaged in play with an object (at 18 months; see also Elsner & Aschersleben, 2003). Together, these findings suggest that learning about actions and interactions through observation shows a more prolonged development than learning the same information from first-person experience. The possibility that this pattern in development derives from analogical processes is a question for future research.

In summary, the current study provides support for the proposal that self-produced actions provide unique information for the development of action understanding. Over the course of early development, infants become able to act in increasingly well-structured goal-directed ways (Piaget, 1954; von Hofsten, 2004). In doing so, the infant may create for herself the experiences that support further development. As infants gain motor experience, they are also exposed to a myriad of other information through observation. Importantly, motor experience might act not only to support recognition of a matched action, but may also serve as a base for analogical extension, thus facilitating the development of goal recognition for increasingly broad and complex actions. Whether and how this might occur on a neural level is an intriguing question for future research (see Gerson, under review, for discussion).

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Figure 1

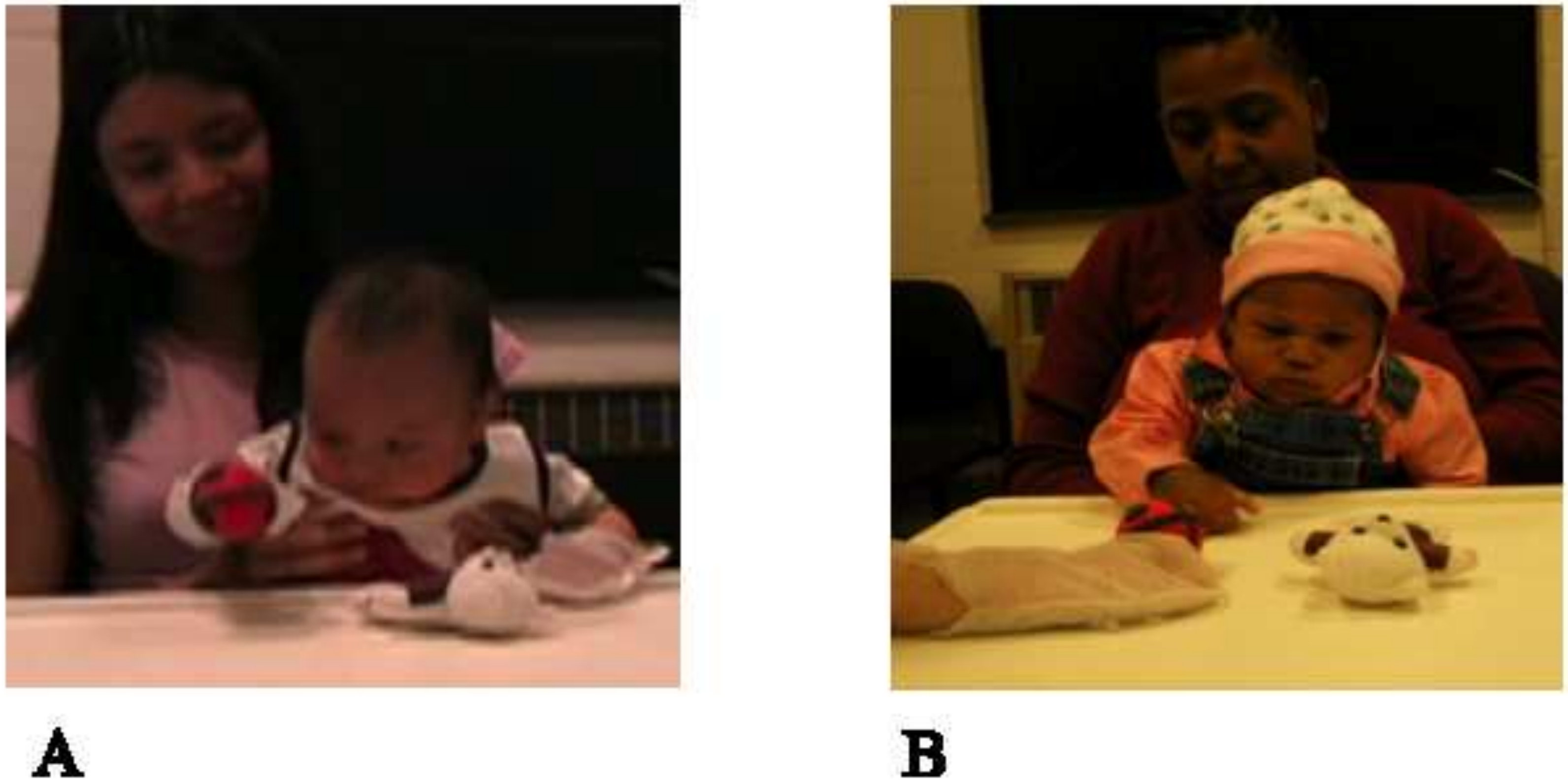

Figure 1. Infants in the active condition (A) and observational condition (B) during mittens training

Figure 2

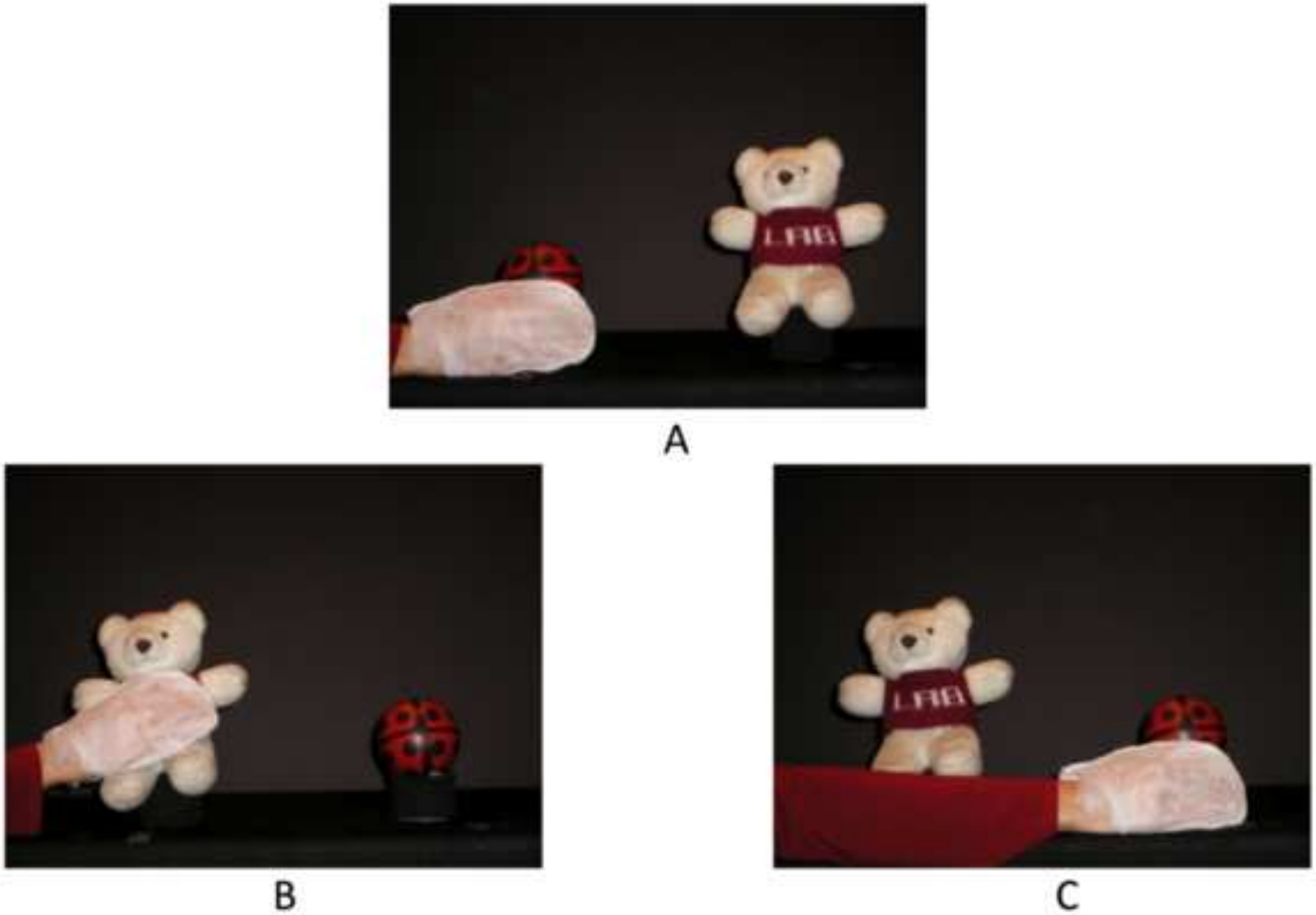

Figure 2. Infants were habituated to a reach for one of two toys (A) and then saw new-goal (B) and old-goal (C) test-trials

Figure 3

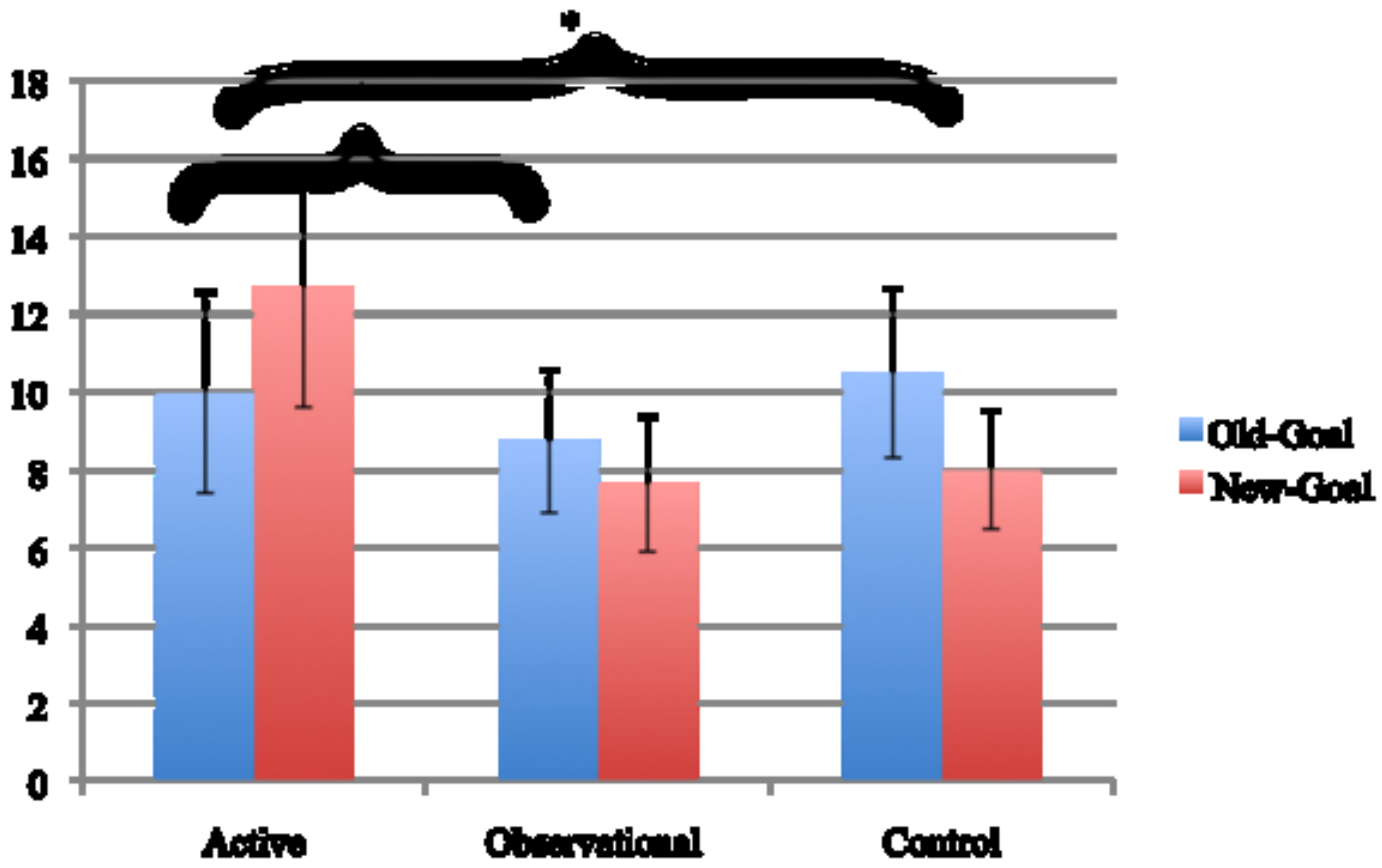

Figure 3 Untransformed means and standard errors for average looking to old-goal versus new-goal trials across conditions. Infants in the active condition looked longer to new-goal than old-goal trials but infants in the other two conditions did not show a systematic preference.

Figure 4

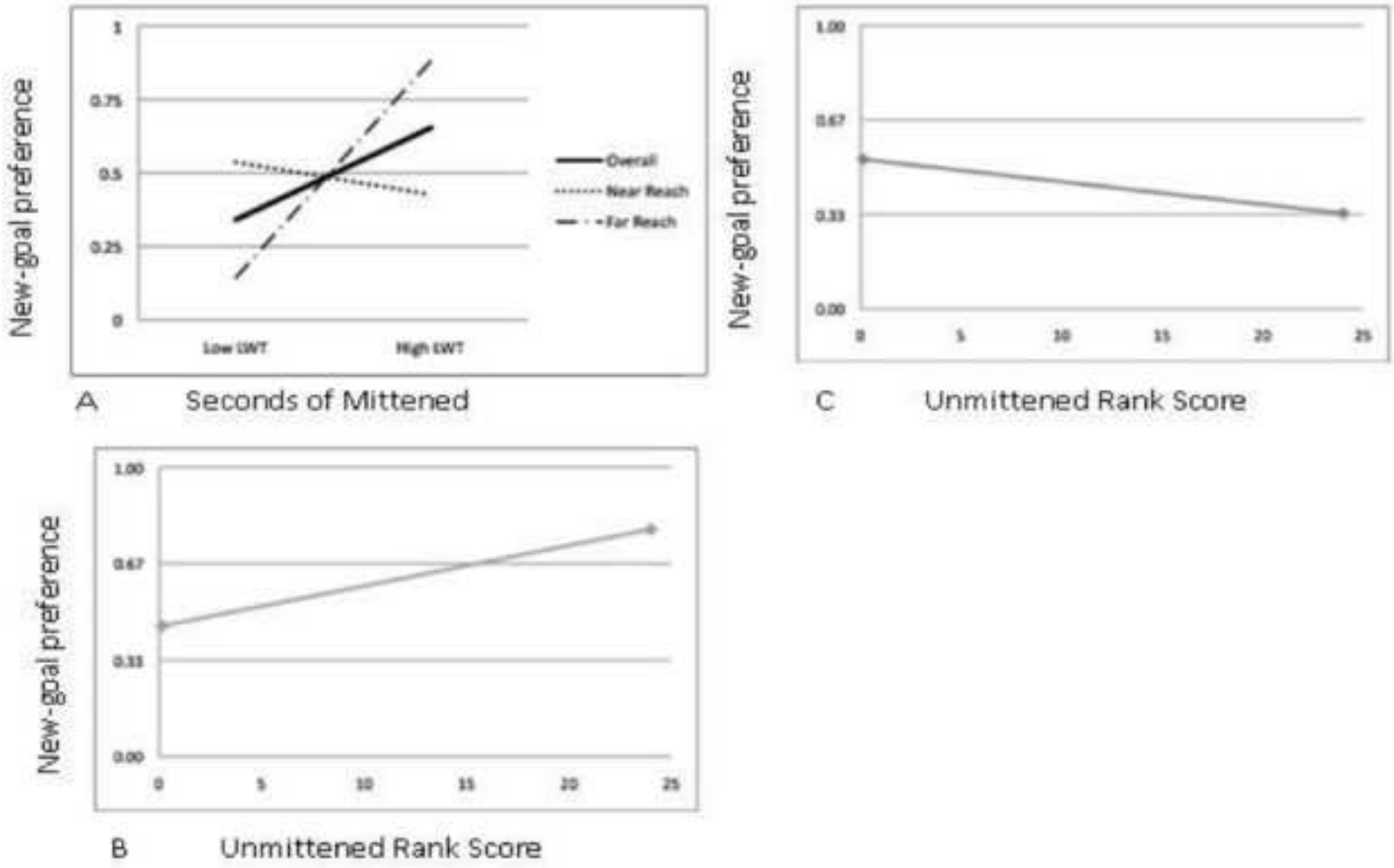

Figure 4. Interaction between mittened activity and reach for new-goal preference in active condition (A), relation between unmittened activity and new-goal preference in observational condition (B), and no relation between unmittened activity and new-goal preference in the control condition (C)

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