Ten-month-old infants use prior information to identify an actor’s goal

Jessica A. Sommerville and Catharyn C. Crane

Abstract

For adults, prior information about an individual's likely goals, preferences or dispositions plays a powerful role in interpreting ambiguous behavior and predicting and interpreting behavior in novel contexts. Across two studies, we investigated whether 10-month-old infants’ ability to identify the goal of an ambiguous action sequence was facilitated by seeing prior instances in which the actor directly pursued and obtained her goal, and whether infants could use this prior information to understand the actor’s behavior in a new context. Experiment 1 demonstrated that the goal preview impacted infants’ subsequent action understanding, but only if the preview was delivered in the same room as the subsequent action sequence. Experiment 2 demonstrated that infants' failure to transfer prior goal information across situations arose from a change in the room per se and not other features of the task. Our results suggest that infants may use their understanding of simple actions as a leverage point for understanding novel or ambiguous actions, but that their ability to do so is limited to certain types of contextual changes.

Introduction

The ability to understand goals or intentions is an important and prevalent aspect of mature and developing cognition. Understanding the goal structure of actions and events guides language acquisition (Baldwin & Moses, 2001; Tomasello, 2001; Woodward, 2004), contributes to social learning (Carpenter, Call & Tomasello, 2002; Meltzoff, 1995; Want & Harris, 2001), and aids identification of cultural artifacts, including tools and representations (Gelman & Bloom, 2000; Bloom & Markson, 1998). Goals and intentions play a critical role in understanding others’ behavior, serving as central explanatory and descriptive constructs in adults’ and children’s folk psychology (D’Andrade, 1987; Wellman, 1990). Appreciating goals or intentions is particularly important for understanding the meaning behind ambiguous actions, and for generating expectations about others’ behavior in novel contexts. Imagine watching a colleague grasp the sides of a soda pop machine and begin to methodically rock the machine back and forth. Prior knowledge that your colleague is a soda pop-lover immediately clarifies the purpose of her ambiguous actions (freeing a trapped pop can), and provides a basis for predicting what sort of beverage to serve to your colleague at your first dinner party.

A variety of research suggests that the ability to understand the goal structure of action emerges in infancy. After seeing an actor reach repeatedly for one of two toys sitting on a stage, 6-month-old infants look preferentially to events that disrupt the relation between the actor and her goal object versus events that feature a change in the spatial location of the reach, suggesting that it is by this age that infants selectively encode the goal of a simple reach and grasp (Woodward, 1998). Over the next 6 months of life infants’ action understanding becomes increasingly elaborate and sophisticated. By 1 year of age infants represent the goal-directed nature of referential acts (Woodward, 2003; Woodward & Guajardo, 2002) and novel actions (Kiraly, Jovanovic, Prinz, Aschersleben & Gergely, 2003), segment ongoing action into goal-relevant units (Baldwin & Baird, 2001; Baldwin, Baird, Saylor & Clark, 2001), interpret actions flexibly depending on context (Behne, Carpenter, Call & Tomasello, 2005; Gergely, Nadasdy, Csibra & Biro, 1995) and extend attributions of goal-directedness to animated objects (Csibra, Gergely, Biro, Koos & Brockbank, 1999; Gergely & Csibra, 2003; Gergely et al., 1995; Kuhlmeier, Wynn & Bloom, 2003; Luo & Baillargeon, 2005; Shimizu & Johnson, 2004).

One important aspect of understanding goal-directed action involves the ability to recognize that actions within a sequence are directed toward an ultimate goal. Consider the following example: a woman picks up a pen, opens a recipe book, writes down some notes on a piece of paper, grabs her car keys and exits the house. Adults recognize the proximal goals underlying each of these individual acts (e.g. reaching for the pen as directed toward the pen), but also recognize each act as a step in a larger overall plan (a trip to the grocery store). Recent evidence suggests that this latter ability emerges between 10 and 12 months of age (Sommerville et al., 2005; Sommerville & Crane, 2007).
second year of life, children can productively use prior information regarding an individual's goals, by a number of factors. Chief among these factors is the ability to encode the actor's goal in the habituation event, the toys were reversed and infants saw test events in which the actor acted only on the cloth. On new goal test events, the actor grasped the same cloth she had initially, which supported a different toy than the one she acted toward during habituation events. On new means test events, the actor grasped the other cloth, which supported the toy she had grasped during habituation trials. Twelve-month-old infants showed a significant preference for the new goal events, suggesting that after seeing the actor pull the cloth to get the toy, they understood that the actor's subsequent actions on the cloth were directed toward the toy and not the cloth itself. Thus, by 1 year of age infants appear to understand the ultimate goal of simple action sequences (see also Woodward & Sommerville, 2000).

In contrast, 10-month-old infants, as a group, showed no preference for either type of test event. However, infants of this age also took part in a task that assessed their ability to solve a cloth-pulling task in their own actions. Performance on this task was related to infants' ability to encode the actor's goal in the habituation paradigm: infants who were skilled cloth pullers looked longer at the new goal event than the new means event, whereas infants who were unskilled cloth pullers showed the reverse pattern of looking. Recent research with younger infants provides further support for the claim that infants' own developing action capabilities contribute to their action understanding. Providing pre-reaching 3.5-month-olds with a reaching intervention that enabled them to apprehend objects also facilitated their ability to appreciate the goal-directed nature of another person's reach and grasp (Sommerville, Woodward & Needham, 2005).

The aforementioned findings suggest that infants' action understanding is tethered to their ability to execute action sequences. Mature reasoners, however, are not limited to understanding actions they can perform: the consummate couch potato and soccer afficionado can nevertheless identify the intention underlying Rivaldo's bicycle kick. For adults, online action processing is heavily influenced by a number of factors. Chief among these factors is the role of context in infants' ability to encode and retrieve experienced and witnessed actions (Borovsky & Rovee-Collier, 1990; Butler & Rovee-Collier, 1989; Barnat, Klein & Meltzoff, 1996; Hanna & Meltzoff, 1993; Hartshorn, Rovee-Collier, Gerhardtstein, Bhatt, Klein, Aaron, Wondoloski & Wurtzel, 1998; Hayne, Rovee-Collier & Borza, 1991; Klein & Meltzoff, 1999; Learmonth, Lambert & Rovee-Collier, 2004). These studies have revealed a high degree of context specificity in young infants' memories. Butler and Rovee-Collier (1989) found that after 3-month-old infants learned to kick their foot to make a mobile move, their retention of this contingency was impaired across delays of more than 1 day if the test stimulus involved a new cue (a change to the mobile) or a new context (a change to the crib liner). Similar findings have been documented in 6-month-olds (Borovsky & Rovee-Collier, 1990), and changes in cues and context from encoding to reminder treatments also impair the efficacy of these reminders on infants’ subsequent memory performance (Borovsky & Rovee-Collier, 1990; Butler & Rovee-Collier, 1989; Hayne et al., 1991).
Seminal studies by Meltzoff and colleagues, using a deferred imitation paradigm, provide important information regarding when infants begin to generalize modeled actions across changes in context. Early studies investigated the impact of a change in room from encoding to test in conjunction with other factors (delay: Hanna & Meltzoff, 1993; object color and size: Barnat et al., 1996). These studies revealed that although successful imitation occurred, imitation scores were reduced compared to conditions in which no delay and context change was present (Hanna & Meltzoff, 1993) and in conditions in which infants were given the opportunity to imitate in the same room and with the same objects used during the encoding phase (Barnat et al., 1996). To disentangle the effect of these factors, Klein and Meltzoff (1999) independently manipulated length of delay and context change. Twelve-month-old infants were tested across two different types of contextual changes: a change from an orange-and-white polka dot tent to a normal laboratory room, and a change from home to a normal laboratory room. Infants’ recall memory was unaffected by changes in context, both when recall was tested 3 minutes after the encoding phase, and up to 4 weeks later (see Hayne, Boniface & Barr, 2000, for similar findings suggesting that 12- and 18-month-old infants generalize across a change in context from the laboratory to home).

Recent research suggests that the ability to recall information in a new context may begin to emerge several months prior to the end of the first year of life. Learmonth et al. (2004) tested 6-, 9- and 12-month-old infants in a paradigm in which infants watched modeled actions on a hand puppet while sitting on a mat in a room in their homes. Infants were tested 24 hours later in either the same context or a different context (infants were tested on a different mat, in a different room of the house, or with both a different mat and in a different room). Nine- and 12-month-old infants, but not 6-month-old infants, generalized imitation across a change in both mat and room. Recent studies provide converging evidence that 6-month-old infants fail to generalize across contextual changes (Hayne et al., 2000), and demonstrate that the ability to generalize across contextual changes emerges by roughly 9 months of age as measured by operant conditioning and deferred imitation paradigms (Hartshorn et al., 1998; Herbert, Gross & Hayne, 2007).

Taken together, these findings raise the possibility that infants may possess the prerequisite abilities to extend goal expectations across contextual changes. Prior studies have demonstrated that infants expect agents to continue to pursue similar goals across very minor changes to the visual display in which the goal-directed action is embedded (Kuhlmeier et al., 2003; Song, Baillargeon & Fisher, 2005; Song & Baillargeon, 2007). Of interest in the current study was whether 10-month-old infants could extend goal attributions across a more dramatic and ecologically valid change in context: a change in the room in which the actor pursued her goal.

In the current study, during prior information trials infants saw an actor reach toward, grasp and pick up one of two toys sitting on a stage floor. Infants subsequently participated in a habituation paradigm that assessed their ability to identify the goal of an action sequence that infants of this age typically find ambiguous: one in which an actor uses a support to obtain an out-of-reach toy (Sommerville & Woodward, 2005a). This paradigm was conducted in either the same room in which the prior information trials had been delivered, or in a different room, in order to assess infants’ ability to extend goal expectations across contexts. If infants capitalize on prior information to disambiguate a subsequent action sequence, we predicted that infants should succeed at identifying the toy as the goal of the action sequence.

**Experiment 1**

**Method**

**Participants**

Forty-eight infants (18 girls and 30 boys; age range = 9 months, 15 days to 10 months, 15 days, mean age = 9 months, 26 days) participated in the experiment. All infants were full term (at least 37 weeks gestation), typically developing, and from a large metropolitan city. Participants were recruited from a database maintained by the university at which the research was conducted. Based on parental report of ethnicity, 37 infants were classified as Caucasian, three infants as Asian, one infant as Hispanic, and seven infants as a mixed race or unlisted ethnicity. Infants were randomly assigned to either the same room condition (mean age = 9 months, 28 days), or the different room condition (mean age = 9 months, 25 days). Sixteen additional infants completed the experiment, but were not included in the final sample because: they became fussy during the procedure (n = 6), they refused to watch the presentation of prior information or test trials (n = 5), or there was an experimental error (n = 5).

**Procedure**

*Prior information trials.* Infants received prior information trials in either the habituation room, or in a tabletop testing room that was roughly 4 meters down the hall from the habituation room.

The tabletop testing room is a rectangular room, 287 × 380 cm wide, with three brick walls, one light blue wall, and a small window, covered by opaque black film. Infants sat on their caregiver’s lap on a swivel chair, approximately 122 cm in front of a table (97 × 61 × 122 cm). The table supported a green plastic frog and a red plastic fish, sitting roughly 30 cm apart. An actor sat behind the table. This display was located in the back corner of the room, such that infants faced away from...
the door, with the window located on the infants’ left side. A video camera on a tripod was positioned behind the actor to capture infants’ eye gaze. The images from this camera fed to an adjacent room where an observer coded infants’ eye gaze online. One of the long walls behind the infant contained two long shelves containing various supplies. The room was otherwise empty.

The habituation room is a larger rectangular room (584 × 330 cm) containing a habituation booth fashioned from black curtains (370 × 130 cm). Infants sat in a high chair in the habituation booth approximately 122 cm in front of a stage. The stage (122 × 49 × 62 cm) supported the green frog and red fish, sitting approximately 30 cm apart. An actor sat behind the stage. A black screen that could be raised manually to block the infants’ view of the display rested in front of the stage. A video camera was mounted behind the actor to capture infants’ eye gaze. During the experiment, the overhead lights were turned off, and two spotlights positioned at the top of the stage were lit in order to illuminate the display. An observation station with a computer on a desk was located outside the habituation booth, in the left corner of the room, obscured from the infants’ view.

During prior information trials, infants sat in a high chair (same room condition) or on their parent’s lap (different room condition). Prior information trials began when either a screen was lowered to reveal the stage (same room condition) or the primary experimenter gestured for the parent to turn the swivel chair to face the table (different room condition). The actor sitting behind the stage or table said, ‘Hi’, and looked toward first the target toy and then the other toy. She then said, ‘Look’, picked up the target toy, smiled, and said, ‘Wow’, and held this pose for the duration of the trial. Infants looking to the event was timed from when the actor stopped moving until the infant looked away for 2 seconds. Trials were terminated after the infant looked away for 2 seconds. At the end of each trial, the screen was raised, then lowered to begin the next trial. Habituation trials were presented until a criterion of habituation had been met or until the infant viewed 14 trials, whichever came first. The habituation criterion was a 50% decline in looking time on three successive trials, relative to looking time on the first three consecutive trials. Thus, each infant received between six and 14 habituation trials. The toy on the infants’ right and the side to which the actor reached were counterbalanced across infants.

After the habituation criteria were met, the locations of the toys were reversed (while the display was hidden from infants’ view), and infants subsequently viewed six test trials. During new goal trials, the actor grasped the same support that she had during habituation trials, which now supported a new toy. On new means trials, the actor grasped a different support than she had initially, which supported the target toy that she acted toward during habituation trials. Infants saw three trials of each type, presented in alternation. The test trial presented first was counterbalanced across infants.

Coding

During both the prior information trials and the habituation paradigm infants’ looking time was calculated online by an observer who watched the infant on a video monitor. The observer pushed a computer key when the infant was looking at the area encompassing the supports, toys and the actor. Looking time was calculated from the time the actor stopped moving until the infant looked away for 2 seconds. Trials were terminated after the infant met the 2-second looking criterion, or after the maximum trial length was reached (30 seconds for prior information trials; 60 seconds for habituation and test trials). The observer was unaware of the specific events that the infant was viewing and was able to see only the infant on the monitor.

Reliability

After the experiment, a secondary observer, who was unaware of specific events that infants watched, coded
the infants’ gaze from videotape. Observers were counted as agreeing if they identified the same look away as ending the trial. The primary and secondary observer agreed on the ending of 95% of test trials for the same room condition and 96% of test trials for the different room condition. To ensure that disagreements did not occur systematically in favor of the hypothesis, the disagreements were categorized into two groups: those that would have contributed to the hypothesized pattern of findings and those that would have worked against the hypothesized pattern of findings. Disagreements were randomly distributed across these categories for both the same room condition ($\chi^2(df = 1) = .6, p > .8$) and the different room condition ($\chi^2(df = 1) = 1.2, p > .3$).

**Results and discussion**

**Prior information trials**

Infants’ looking to the prior information trials is depicted in Figure 1. To ensure that infants in the same room and different room conditions were equally attentive to the prior information trials we summed infants’ looking times across the five prior information trials and compared looking duration across conditions. Infants’ attention to the prior information trials did not vary as a function of condition (same room condition: $M = 63.2, SE = 4.8$; different room condition: $M = 70.6, SE = 6.1$; ns). Thus, infants in both conditions attended equally to the prior information trials.

**Habituation paradigm**

**Habituation trials.** Infants’ rate of habituation across the two conditions did not differ. Infants in the same room condition habituated after an average of 6.9 trials ($SE = .4$) and infants in the different room condition habituated after an average of 7.8 trials ($SE = .6$; ns). Moreover, infants’ looking duration to the first three habituation trials (same room: $M = 33.9, SE = 3.6$; different room: $M = 28.5, SE = 2.1$; ns) and last three habituation trials (same room: $M = 11.0, SE = 2.1$; different room: $M = 9.3, SE = 1.0$; ns) did not vary according to condition. Thus, infants in both conditions were equally attentive to the habituation event.

![Figure 1 Infants’ looking to prior information trials as a function of condition (Experiments 1 and 2).](image1)

![Figure 2 Infants’ looking to test events (standard errors) as a function of condition (Experiments 1 and 2).](image2)

**Test trials.** Three infants (different room $n = 1$; same room $n = 2$) were excluded from test trial analyses because their total looking on test trials was more than 2 standard deviations above the mean. A preliminary analysis revealed that the side to which the presenter reached first, the toy on the infant’s right, and the test event shown first had no impact on infants’ attention to the test events. Subsequent analyses collapsed across these variables.

We summed infants’ looking across the test events and entered these scores into an ANOVA with trial type (new goal versus new means event) as the within-subjects variable and condition (same room versus different room) as the between-subjects variable. This analysis revealed a significant trial type by condition interaction ($F(1, 43) = 5.4, p < .03$; generalized $\eta^2 = .04$) and no other significant effects. Planned comparisons revealed that infants in the same room condition looked significantly longer to the new goal event ($M = 17.0, SE = 2.1$) than the new means event ($M = 12.9, SE = 1.0$; $t(21) = 2.2 \ p < .02$; generalized $\eta^2 = .19$), whereas looking to the test events did not differ significantly for infants in the different room condition (new goal: $M = 13.6, SE = 1.7$; new means: $M = 16.4, SE = 2.1$; ns). Infants’ looking times to the test events are plotted in Figure 2.

Nonparametric analyses confirmed infants’ differential attention to the new goal and new means test events as a function of condition. Infants were categorized according to the side to which the presenter reached first. Planned comparisons revealed that infants in the same room condition looked significantly longer to the new goal event than the new means event ($M = 21.4, SE = 2.2$; $t(19) = 2.3 \ p < .02$; generalized $\eta^2 = .15$), whereas looking to the test events did not differ significantly for infants in the different room condition (new goal: $M = 13.6, SE = 1.7$; new means: $M = 16.4, SE = 2.1$; ns).

For all independent-sample $t$-tests and Analyses of Variances that reach the level of statistical significance, we report generalized $\eta^2$ as a measure of effect size. Recently, scholars have argued that traditional effect size measures (e.g. Cohen’s $d$) and measures of association (e.g. partial $\eta^2$) can be influenced by the design used to assess the effect, making it difficult to compare findings across studies. Generalized $\eta^2$ removes potential confounding between the effect size measure and the study design (Bakeman, 2005; Olejnik & Algina, 2003). The phi statistic will be reported as measures of effect size for chi-squared tests.

Planned comparisons in both experiments utilized one-tailed $t$-tests because we had a directional prediction regarding infants’ looking: infants were predicted to look longer to the new goal than the new means events.
to condition and looking preference (new goal preference if they looked longer at the new goal events; new means preference if they looked longer at the new means events). A chi-square test revealed an association between infants’ looking preference and condition ($\chi^2(df = 1) = 4.1, p < .04; \phi = .31$). Infants in the same room condition predominantly showed a new goal preference ($n = 14$; new means preference, $n = 6$; no preference, $n = 2$), whereas infants in the different room condition predominantly showed a new means preference ($n = 14$; new goal preference, $n = 9$).

Experiment 2

The findings from Experiment 1 provide evidence that infants can use prior information to disambiguate an action sequence when this information is provided in the same room as the habituation paradigm. These findings also suggest that infants’ ability to use prior information to interpret new actions may be delimited by the context in which the behavior was originally witnessed. However, in addition to the change in room, the same room and different room conditions differed from one another in several other ways. Although infants in the different room condition proceeded from prior information trials to test trials without an intervening break, it is possible that the time passage between these events was slightly longer than it was for infants in the same room condition due to the time required to move infants from one room to another (approximately 30 seconds). In addition, whereas infants in the different room condition underwent motion between these two phases of the study, infants in the same room condition did not. Either of these differences may have contributed to the differential findings.

Experiment 2 sought to investigate the source of infants’ failure to encode the goal of the support sequence in the different room condition. Infants were tested in the same room condition (identical to Experiment 1), or the in-and-out condition. In the in-and-out condition, infants witnessed the prior information trials in the habituation room. After prior information trials, infants were removed from the habituation room, walked halfway down the hall toward the tabletop room, and then returned to the habituation room for the habituation paradigm (a process that took approximately 30 seconds). Infant movement and distance covered were identical to the different room condition of Experiment 1. Thus, success in the in-and-out condition would indicate that it was the change in room per se, rather than other differences between the same and different room conditions, which accounted for infants’ failure in Experiment 1.

Method

Participants

Forty-eight infants (26 girls and 22 boys; age range = 9 months, 19 days to 10 months, 9 days, mean age = 9 months, 21 days) participated in the experiment. All infants were full term (at least 37 weeks gestation), typically developing, and from a large metropolitan city. Participants were recruited from a database maintained by the university at which the research was conducted. Based on parental report of ethnicity, 39 infants were classified as Caucasian, one infant as Asian, and eight infants as a mixed race or an unlisted ethnicity. Infants were randomly assigned to either the same room condition (mean age = 9 months, 19 days), or the in-and-out condition (mean age = 9 months, 23 days). Twenty-six additional infants completed the experiment, but were not included in the final sample because: they refused to watch the presentation of prior information trials or test trials ($n = 12$), they did not habituate ($n = 4$), or there was an experimental error ($n = 10$).

Procedure

Prior information trials. For infants in the same room condition, prior information trials were identical to Experiment 1.

Prior information trials for infants in the in-and-out condition differed in three ways from the same room condition. These variations were designed to directly parallel the testing conditions of the different room condition from Experiment 1. First, in-and-out infants sat on their parent’s lap on a swivel chair, rather than in the high chair. Second, the experimenter did not use the screen to occlude the display from infants’ view in between trials. Instead, prior to the beginning of a trial, the infant and parent sat facing the experimenter with their backs turned to the stage. To begin a trial, the experimenter instructed parents to turn the chair 180 degrees to face the display. When the trial ended, parents were then instructed to turn the chair back around to face the experimenter. Third, after viewing the five prior information trials, parents and infants were asked to exit the room and walk approximately 4 meters down the hall and back (distance and time matched to the different room condition of Experiment 1). Infants were then placed into the high chair. In all other respects prior information trials were identical to those of the same room condition.

Habituation paradigm. Habituation and test trials were identical to those of Experiment 1 for infants in both the same room and in-and-out condition.

3 Infants across the two studies were held to identical exclusion criteria. Only infants in Experiment 2 were excluded due to failure to habituate ($n = 4$) because all infants in Experiment 1 habituated. A greater number of subjects were lost in Experiment 2 (versus Experiment 1) due to an increase in experimental error and an increase in the number of infants that would not watch the presentation of prior information or test trials. This latter number may have increased from Experiment 1 because infants received all trials in a single room. Ongoing studies have revealed similar trends: attrition is lowered when looking time tasks take place across two different rooms versus within a single room.
Coding and reliability. Coding of infant eye gaze was identical to Experiment 1. A secondary observer coded infants’ looking duration offline. The primary and secondary coder agreed on the ending of 94% of trials for the same room condition and 96% for the in-and-out condition. Disagreements were randomly distributed in both the same room ($\chi^2(df = 1) = .48, p > .99$) and in-and-out condition ($\chi^2(df = 1) = 1.3, p > .99$).

Results and discussion

Prior information trials
Infants’ looking to the prior information trials is depicted in Figure 1. We summed infants’ looking times across the five prior information trials and compared looking duration across conditions. Infants’ attention to the prior information trials varied as a function of condition (same room condition: $M = 51.1, SE = 4.5$; in-and-out condition: $M = 91.7, SE = 5.3$; $t(46) = 6.6, p < .0001$; generalized $\eta^2 = .48$).

Infants in the in-and-out condition may have been more attentive to the prior information trials than infants in the same room condition because they viewed these trials sitting on their parent’s lap, whereas infants in the same room condition viewed prior information trials while sitting in a high chair. Infants in the different room condition in Experiment 1 also viewed prior information trials while on the parent’s lap and yet showed equivalent looking times to infants in the same room condition. However, these trials were not delivered while infants were sitting in the habituation booth. It may have been the combination of these two factors that contributed to in-and-out infants’ longer looking on prior information trials.

Habituation paradigm

Habituation trials. Infants’ rate of habituation across the two conditions did not differ. Infants in the same room condition habituated after an average of 7 trials ($SE = .4$) and infants in the in-and-out condition habituated after an average of 7.5 trials ($SE = .4; ns$). Moreover, infants’ looking duration to the first three habituation trials (same room: $M = 33.3, SE = 3.7$; in-and-out: $M = 32.7, SE = 3.2; ns$) and last three habituation trials (same room: $M = 11.1, SE = 1.3$; in-and-out: $M = 9.2, SE = 1.1; ns$) did not vary according to condition. Thus, infants in both conditions were equally attentive to the habituation event.

Test trials. Three infants (all in-and-out condition) were excluded from test trial analyses because their total looking on test trials was more than 2 standard deviations above the mean. A preliminary analysis revealed that the side to which the presenter reached first, the toy on the infant’s right, and the test event shown first had no impact on infants’ attention to the test events. Subsequent analyses collapsed across these variables.

We summed infants’ looking across the test events and entered these scores into an ANOVA with trial type (new goal versus new means event) as the within-subjects variable and condition (same room versus in-and-out) as the between-subjects variable. This analysis revealed a significant effect of trial type ($F(1, 42) = 5.9, p < .02$; generalized $\eta^2 = .12$) and no other significant effects. Planned comparisons revealed that infants in both conditions looked significantly longer to the new goal event (same room: $M = 18.4, SE = 2.0$; in-and-out: $M = 15.3, SE = 2.2$) than the new means event (same room: $M = 14.6, SE = 1.1, t(23) = 1.6, p < .05$; in-and-out: $M = 11.9, SE = 1.6$; $t(20) = 2.0, p < .03$). Infants’ looking times to the test events are plotted in Figure 2.

Comparisons with Experiment 1
We next compared looking times to the test events for infants tested in the different room condition (Experiment 1) to infants tested in the in-and-out condition (Experiment 2). This comparison provides the cleanest assessment of whether the change in context per se affected infants’ attention to the test events, because these conditions were closely matched in terms of duration of time and amount of movement that infants experienced between prior information trials and the habituation paradigm. We entered infants’ looking scores into an ANOVA with trial type (new goal versus new means event) as the within-subjects variable and condition (in-and-out versus different room) as the between-subjects variable. This analysis revealed a significant trial type by condition interaction ($F(1, 43) = 4.6, p < .04$; generalized $\eta^2 = .04$), and no other significant effects. Taken together, these findings suggest that it was the change in context, and not other differences between the same and different room condition, that impaired infants’ ability to use prior information about an actor’s goal to disambiguate the support sequence.

Looking on prior information trials, habituation trials and test trials

We next investigated whether individual differences in infants’ attention to prior information trials affected their ability to use this information to disambiguate the support sequence. We conducted a correlational analysis on infants’ overall looking during prior information trials, and infants’ sensitivity to the goal of the support sequence (calculated by subtracting infants’ summed looking to the new means event from infants’ summed looking to the new goal event). Given prior work suggesting that infants readily extract goal information from simple reach and grasp acts by at least 6 months of age (e.g. Woodward, 1998; Woodward, 2003), we speculated that it was exposure to the goal-directed act, rather than the amount of time spent looking at the outcome of the act (that could reflect individual differences in interest in the objects or individual featured in the event), that enhanced...
infants’ subsequent understanding of the support sequence. This analysis revealed no relation between these two measures, for the sample as a whole, as well as for each condition independently (ns). These findings suggest that any differences between conditions in attention to the prior information trials do not account for differences in attention to the test events, and are consistent with the possibility that mere exposure to the actor’s goal during prior information trials enhanced infants’ understanding of the sequence.

We also examined the relation between the number of habituation trials that infants viewed and their preference for the new goal event. One interpretation of our findings is that providing infants with prior information trials may merely increase the number of goal-directed acts that they see performed by the actor, thus enhancing infants’ ability to identify the actor’s goal. If this is the case, the number of habituation trials that infants view should impact their ability to identify the goal of the support sequence (recall that all infants saw five prior information trials). However, the number of habituation trials that infants viewed was unrelated to the extent of their preference for the new goal event, for the sample as a whole, and for each individual condition (ns).

General discussion

To date, a number of mechanisms have been proposed to account for advances in infants’ action understanding, including cue-based bootstrapping (Biro & Leslie, in press), action segmentation (e.g. Baldwin & Baird, 2001; Baldwin et al., 2001), the ‘like me’ hypothesis (e.g. Meltzoff, 2005, 2007), alignment of intentional relations (Barresi & Moore, 1996; Moore, 2006) and embodied action representations (Sommerville & Decety, 2006; Sommerville, Hildebrand & Crane, 2008; Woodward, 2005). The findings from the current study provide evidence for another mechanism supporting infants’ ability to understand others’ actions. Specifically, we suggest that infants rely on prior information about an actor’s goal, extracted from simple, familiar actions, to disambiguate more complex and/or ambiguous action sequences. The ability to do so represents an important means by which infants may come to understand novel actions, particularly those that infants do not have the opportunity to perform.

How does prior goal information enhance infants’ understanding of action sequences? Prior expectations about the object that an actor is likely to act toward could influence subsequent processing and memory of action sequences, which in turn facilitates infants’ ability to identify the actor’s goal. Indeed, a variety of work suggests that infants’ action representations are organized in terms of anticipated effects (Hauf, Elsner & Aschersleben, 2004; Kiraly et al., 2003), and recent evidence suggests that one of the main ways in which infants’ own action representations may influence their perception of others’ actions is through anticipation of action outcomes (Sommerville et al., 2008).

It is also possible that prior information regarding the actor’s likely goal facilitates infants’ causal understanding of the sequence. Sommerville and Woodward (2005b) demonstrated that 10-month-old infants, as a group, fail to appreciate the need for contact between the toy and support in order for the toy to move when the support is pulled. On one hand, providing infants with a preview of the actor’s goal prior to showing them the support sequence may lead infants to assume a causal relation between the act of pulling the support and the act of grasping the toy even if they are unaware of the exact mechanism by which these two events are related. Alternatively, awareness of the actor’s goal object might enhance infants’ ability to attend to the relation between the toy and support leading infants to identify the causal constraints of the sequence. This account is consistent with recent research demonstrating that infants’ understanding of human agency influences causal perception (Sommerville & Shultz, 2007) and evidence that adults consider intentionality when making causal judgments (Chaingneau, Barsalou & Sloman, 2004).

Are there alternative interpretations of our findings? Perhaps instead of conveying information about the actor’s intention toward the toy, prior information trials merely served to entrain infants’ attention to the target toy (just as shining a spotlight on the target toys during prior information trials might), and it is this perceptual highlighting of the target toy that accounts for our findings. We have several objections to such a perceptual salience account.

First, it is important to note that a perceptual salience account does not immediately and logically lead to a prediction of longer looking to the new goal test trials than to the new means test trials. In fact, under one interpretation, perceptual highlighting of the target toy during prior information trials might lead to just the opposite preference, by making the toy less interesting during habituation trials, leading infants to focus more heavily on the support that the actor acts on. Indeed, prior work suggests that perceptual highlighting on its own is insufficient to support goal encoding in a simple reach and grasp paradigm (Woodward, 1998). Second, because information trials were identical across the same and different room conditions so too was the extent to which the toy was made salient during these trials. Despite this equivalence, only infants in the same room condition encoded the goal of the support sequence. Taken together, these findings suggest that prior information trials do not influence infants’ encoding of the goal of the support sequence merely by making the target toy perceptually salient.

Although infants succeeded in using prior goal information to disambiguate the goal of the support sequence, they failed to extend this information to a new context. One possibility is that differences between the same and

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4 We thank an anonymous reviewer for bringing this alternative interpretation to our attention.
different room conditions may have led to differential encoding of the information presented during prior information trials. However, the equivalence of infants’ looking times to the prior information trials across the different room and same room conditions suggests that encoding differences cannot account for differential looking patterns on test trials.

Another possibility is that infants’ lack of transfer in the different context condition may reflect a retrieval failure. Recent research using a deferred imitation paradigm suggests that the ability to recall information across contexts is present as early as 9 months of age (Learmonth et al., 2004). However, infants in the Learmonth et al. (2004) study were tested in two familiar rooms (in the infants’ home), whereas infants in our study were tested in two novel rooms. It is possible that the extent to which infants are familiar with the encoding and test context may impact infants’ generalization abilities. Future work should address this possibility.

Infants’ retrieval abilities are also influenced by individual differences in infants’ experience prior to entering the experimental setting. Infants’ locomotor experience has been hypothesized to contribute to more flexible memory in experimental setting. Infants’ locomotor experience has been hypothesized to contribute to more flexible memory across contexts is present as early as 9 months of age (Learmonth et al., 2004). Herbert et al. (2007) recently assessed the relation between independent locomotion and memory by testing crawling and non-crawling 9-month-old infants in a deferred imitation paradigm. Infants watched a target behavior and were given the opportunity to reproduce the behavior 24 hours later with the same stimulus in the same room (no change condition) or a different stimulus in a different room (cue and context change condition). Both crawling and non-crawling infants reproduced the target action in the no change condition, but only crawling infants reproduced the target action in the cue and context change condition. The authors suggested that crawling provides infants with the opportunity to retrieve memories across multiple contexts, which in turn facilitates memory retrieval more broadly. Future research can examine whether similar links exist between infants’ crawling ability and their ability to transfer goals across contexts.

Another possibility is that the impact of contextual changes may be task or domain specific. Moore and Meltzoff (2004) investigated 14-month-old infants’ ability to search for an object that had been hidden in a container following a 24-hour delay. Infants searched successfully for the object when tested in the same room in which the initial hiding event took place, but did not search if the room had been changed in several salient ways, even though the original hiding container remained the same. The impact of contextual change may vary as a function of domain tested or task utilized due to differing task demands and/or because infants may remember prior information but be reluctant to apply it to the new context under some circumstances.

Infants in the current study may have remembered the actor’s prior actions, but perhaps did not deem them relevant to the current context. Prior work has established that there are developmental changes between roughly 4 and 10 years of age in children’s readiness to generalize behavior across contexts. Younger children are less likely than older children to use prior behavior in one situation to predict future actions in another context (Aloise, 1993; Miller & Aloise, 1989; Rotenberg, 1982), and require more instances of a behavior to attribute an enduring personal characteristic (Aloise, 1993; Boseovski & Lee, 2006). However, this reluctance is not due to domain-general limitations in young children’s generalization abilities. Kalish (2002) found that whereas 5-year-olds readily generalize object affordances and biological properties of non-human animals across contexts, they do not predict consistency in psychological characteristics (e.g. people’s choices and decisions). Thus, it is possible that at 10 months of age, infants’ lack of transfer to a new context is limited to reasoning about other people’s actions.

There are several pieces of evidence that provide support for this position. First, whereas deferred imitation studies typically assess memory for witnessed actions across substantial delays (of 24 hours or more; e.g. Klein & Meltzoff, 1999; Learmonth et al., 2004; Harsthorn et al., 1998), infants were tested directly after seeing information presented in prior information trials. By assessing transfer immediately after infants witnessed the target behavior, we reduced the likelihood that infants failed to retrieve prior information. Second, previous studies have demonstrated that infants, at 10 months and younger, succeed at transferring action goals from one room to another under different circumstances. In these studies (Sommerville et al., 2005; Sommerville et al., 2008) infants received training and experience performing a particular goal-directed action or action sequence, and their subsequent understanding of the goal of that action or action sequence in another person’s actions was assessed via a habituation paradigm that was conducted in another room. Infants encoded the goal of the behavior featured in the habituation paradigm, following training in the other room.

Third, if infants’ lack of generalization was due to a retrieval failure, recovery scores from the last prior information trial to the first habituation trial should be greater for infants in the different room condition than infants in the same room condition (because the elements involved in the support event should appear more novel to infants in the different room condition than infants in the same room condition). Comparisons of recovery scores revealed that the extent of recovery did not differ as a function of condition (ns). Future work can directly investigate the source of infants’ lack of transfer by testing infants on two tasks that are matched in terms of their task demands and transfer requirements, but vary in terms of whether or not they involve inferences about goal-directed behavior.

In contrast to the current findings, and research with children, several authors have recently argued that infants attribute specific dispositions and preferences to agents and use this information to make predictions about how an agent will act in a novel context (Kühlmeier et al.,...
that infants also draw on prior information specifying understanding of goal-directed action by demonstrating (Sommerville, 2001). The present study adds to the literature on infants' formative role in their understanding of the actions of others (Sommerville & Woodward, 2005a, 2005b; Sommerville et al., 2005; Woodward, 2005b; Woodward & Guajardo, 2002; Woodward, Sommerville & Guajardo, 2001). The present study adds to the literature on infants' understanding of goal-directed action by demonstrating that infants also draw on prior information specifying an actor's action tendencies to identify others' goals. Specifically, we argue that infants' understanding of, and exposure to, familiar actions can bootstrap their understanding of ambiguous action sequences. For mature reasoners, online action processing is heavily influenced by prior information about an individual's goals, intentions, preferences and dispositions. Thus, infants' ability to draw on the past to interpret the present represents an important advance in their developing understanding of others' behavior.

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