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Infant Categorization of Path Relations During Dynamic Events

Shannon M. Pruden
Florida International University

Sarah Roseberry
University of Washington

Tilbe Göksun
University of Pennsylvania

Kathy Hirsh-Pasek
Temple University

Roberta M. Golinkoff
University of Delaware

Fundamental to amassing a lexicon of relational terms (i.e., verbs, prepositions) is the ability to abstract and categorize spatial relations such as a figure (e.g., *boy*) moving along a path (e.g., *around* the barn). Three studies examine how infants learn to categorize path over changes in *manner*, or how an action is performed (e.g., running vs. crawling). Experiment 1 (n = 60) finds that 10- to 12-month-old English-learning infants categorize a figure's path. In Experiment 2 (n = 27) categorization is disrupted when the ground object is removed, suggesting the relation between figure and ground defines the path. Experiment 3 (n = 24) shows that language may be a mechanism guiding category formation. These studies suggest that English-learning infants can categorize path, a component lexicalized in the world's languages.

Verbs are crucial to the linguistic system not only because they refer to actions, but because they stipulate the grammatical structure of the sentence allowing us to communicate relational concepts such as *who* did *what* to *whom*. Within the last few years, researchers have explored how children acquire a lexicon of verbs and other types of relational terms (e.g., Golinkoff & Hirsh-Pasek, 2008; Hirsh-Pasek & Golinkoff, 2006; Naigles, Hoff, & Vear, 2009; Tomasello & Merriman, 1995). This literature shows that, in most of the languages studied, verbs are more difficult to learn than nouns (Childers & Tomasello, 2006; Fenson et al., 1994; Gentner, 1982; but see Tardif, 1996). Even 5-year-old children and adults can have trouble determining the referent of a verb (Gillette, Gleitman, Gleitman, & Lederer, 1999; Imai et al., 2008; Meyer et al., 2003). While research is beginning to paint a portrait of how children acquire verbs and more broadly, relational terms, there exists a paradox: Despite their difficulty, these words appear in children's earliest vocabularies (Choi, 2006; Choi & Bowerman, 1991; Fenson et al., 1994; Naigles et al., 2009; Tardif, 1996).

Recently, researchers have begun to explore when children have the conceptual knowledge needed to acquire relational terms, such as English prepositions and motion verbs (Casasola & Cohen, 2002; Casasola, Hohenstein, & Naigles, 2003; Göksun, Hirsh-Pasek, & Golinkoff, 2009; Pruden, Göksun, Roseberry, Hirsh-Pasek, & Golinkoff, 2012; Pulverman, Golinkoff, Hirsh-Pasek, & Sootsman Buresh, 2008). This article focuses on what children need to know before they learn their first relational terms such as *over*, *around*, *push*, and *climb*. When do infants have the conceptual knowledge to learn a relational term? More specifically, we ask when can infants categorize one particular component of a motion event, *path*. *Path* is the trajectory a figure

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Correspondence concerning this article should be addressed to Shannon M. Pruden, Department of Psychology, Florida International University, DM 296A, 11200 SW 8th Street, Miami, FL 33199. Electronic mail may be sent to shannon.pruden@fiu.edu.

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takes with respect to a reference or ground object. In the sentence, ''Sally hopped over the puddle,'' ''Sally'' is the figure, the ''puddle'' is the reference or ground object, ''over'' is the preposition encoding the *path* of the figure, and ''hopped'' is the motion verb that includes information about how Sally moved or the manner.

Gentner and Boroditsky (2001) argue that two critical components are necessary to learn a relational term that encodes aspects of motion. Children must first make sense of events in the world. Then they begin to map words onto the actions and objects that comprise the event (see also Gentner & Bowerman, 2009). Golinkoff et al. (2002) suggest that building an arsenal of relational terms requires that infants pay attention to and individuate actions that relational terms encode, form categories of these actions and relations, and map relational terms onto these categories. Thus, the difficulty in learning relational terms can come from one of two sources: the individuation and conceptualization of actions and events or the mapping of words onto these concepts. Theoretically, some conjecture that the concepts needed to learn relational terms are in place at an early age (e.g., Gentner, 1982; Gentner & Boroditsky, 2001; Snedeker & Gleitman, 2004) Some even suggest that the semantic components relational terms label may be built from prelinguistic conceptual primitives from which all other relational terms and concepts are constructed (Jackendoff, 1983; Mandler, 1992, 1996, 2004). These assertions are now being tested (for reviews, see Göksun, Hirsh-Pasek, & Golinkoff, 2010; Pruden, Hirsh-Pasek, & Golinkoff, 2008; Wagner & Lakusta, 2009). The challenge for researchers is determining when infants have the conceptual knowledge to support the learning of these terms.

Verbs and other relational terms do not label whole actions and events. Rather, they label a subset of the many semantic components that co-occur within an event. For example, motion verbs typically express motion along with another semantic component: Manner verbs, like *run*, *jump*, and *swagger*, conflate motion with manner; path verbs, like *exit*, *approach*, and *descend*, conflate motion with path. Infants must recognize those components that are relevant to their language.

Path has been studied in both linguistics and event perception for several reasons. First, *path* is universally codified within the languages of the world (Jackendoff, 1983; Langacker, 1987; Talmy, 1985). Second, *path* may be one of the most central concepts for learning not only motion verbs but also for many other relational concepts. Mandler (2004; 2006) suggests that *path* is used to acquire concepts like animacy and causality. Perhaps then, as Mandler suggests, it is more important to know where you are going, your path, rather than how you got there, your manner. Third, *path* is of interest because it is encoded differently across languages. In English, *manner* is often encoded in the verb, while *path* is usually encoded outside the verb (often in the preposition; e.g., ''A woman ran out of the house''). Spanish, on the other hand, usually encodes the *path* within the verb, while *manner* is optionally encoded in the adverb (e.g., *Una mujer salió de la casa corriendo* which translates to ''A woman exited the house running''). Finally, recent neuroimaging studies with adult participants have shown that distinct brain regions are sensitive to changes in path and manner, suggesting a segregation of neural processing of path and manner (Wu, Morganti, & Chatterjee, 2008). Thus, a thorough investigation of *path* is important for understanding the development of English relational terms, particularly English prepositions.

Some studies have examined infants' ability to notice changes when components in nonlinguistic motion events such as *path* are modified (Casasola et al., 2003; Pulverman & Golinkoff, 2004; Pulverman et al., 2008; Pulverman et al., in press). For example, Pulverman and colleagues (Pulverman & Golinkoff, 2004; Pulverman et al., 2008; Pulverman et al., in press) studied when infants discriminate changes in both *path* and *manner* in nonlinguistic motion events. Seven- to 9-month-olds and 14- to 17-month-olds were habituated to an animated starfish performing a single path with a single manner (e.g., the starfish doing jumping jacks over a ball). After habituating to this event, infants were shown four test trials: a control trial in which the same path and same manner were shown (e.g., jumping jacks over the ball), a path change trial in which the same manner was paired with a novel path (e.g., jumping jacks under the ball), a manner change trial in which a novel manner was paired with the same path (e.g., spinning over the ball), and a path and manner change trial in which a novel manner was paired with a novel path (e.g., bending past the ball). Infants of both age groups dishabituated to the path and manner change test trials (Pulverman & Golinkoff, 2004; Pulverman et al., 2008; Pulverman et al., in press), suggesting that they have the ability to discriminate changes in both path and manner (for similar findings with human agents, see Casasola et al., 2003). Upon further examination, Pulverman et al. (2008) demonstrated that English-learning 14- to 17-month-olds with a rich vocabulary were more sensitive to *manner* changes than their lower vocabulary counterparts. Perhaps a child's initial biases toward the components of actions typically encoded in their language impacts the trajectory of lexical acquisition in the 2nd year.

While these studies suggest that infants are capable of discriminating changes in those components of actions that verbs encode, these skills represent only the tip of the word-learning problem. Words label not single actions, but categories of actions (Markman, 1989; Oakes & Rakison, 2003). *Exiting*, for example, is considered the same action whether one is exiting a train or exiting stage left. After children have the ability to parse events into distinct actions, they must look for similarities across these actions and categorize them before they can map labels to them.

There is some limited evidence that infants are capable of forming categories of spatial relations within events (see Göksun et al., 2009; Golinkoff & Hirsh-Pasek, 2008). For example, Casasola and Cohen (2002) find that English-learning infants form spatial categories corresponding to the English prepositions *in* (containment) and on (support) and the Korean verb *kkita* (meaning ''to put tight-fitting,'' with no distinction between containment and support). Infants were habituated to four different dynamic events each depicting the same spatial relation. They were then tested on an event with a familiar pair of objects in the familiar spatial relation, a familiar pair of objects in a novel spatial relation, a novel pair of objects in the familiar spatial relation, and a novel pair of objects in a novel spatial relation. Nine- to 11-month-olds were able to categorize containment relations, while 17- to 19-month-olds were able to categorize support and tight-fit relations. Similarly, McDonough, Choi, and Mandler (2003) find that English-learning 9-month-olds form categories of containment using a preferential-looking task rather than habituation. While these studies suggest that infants have the ability to categorize containment, support and tight-fit relations, it is unclear whether infants were using dynamic information (e.g., hand places object ''into'' another object) or whether they were simply using the static endpoint of the event (e.g., the result of the static relation ''in'') to form these categories. More recently, Pruden et al. (2012) found that English-learning 13-month-olds form categories of a figure's manner of motion during dynamic events. These recent results provide some of the first evidence that infants can form categories of those semantic components lexicalized in English relational terms and found in dynamic motion events.

While research suggests that 7-month-olds can discriminate changes in linguistically relevant components like path and manner (Pulverman et al., 2008; Pulverman et al., in press; Pulverman & Golinkoff, 2004) and that 13-month-olds can form categories of a figure's manner of motion, a component lexicalized in English motion verbs (Pruden et al., 2012), no research exists on when and how infants come to form categories of a dynamic action component lexicalized primarily in *English spatial prepositions*. The current experiments are the first to address the question of when and how English-learning infants form categories using *dynamic path* information and thus shed light directly on the acquisition of English spatial prepositions and on the few English motion verbs that encode path information (i.e., *ascend, descend, enter, exit*).

Using the same nonlinguistic, *dynamic stimuli* as in Pruden et al. (2012) and Pulverman et al. (2008; Pulverman et al., in press), Experiment 1 tests when infants can abstract an invariant *path* (e.g., *over*) when the figure in the event performs different manners of motion along the same path with respect to a ground object. This design contrasts with Pulverman and colleagues' work in which infants saw only a single path paired with a single manner. Here, we ask whether infants who see a single path paired with *several different manners* can abstract the invariant path. To learn the spatial terms of their language infants not only need to detect but also to categorize the paths they observe, an achievement necessary to form linguistic path categories like ''over'' and ''under.''

Experiment 1: When Can Infants Abstract the Invariant Path From Varying Manners?

Could infants from two age groups, who do not know many (if any) verbs or prepositions (7–9 and 10–12 months), abstract an invariant path across a series of dynamic events that varied in the figure's manner of motion? Infants saw four exemplars of exactly the same *path* across varying *manners*. Our investigation starts at the same age studied by Pulverman and Golinkoff (2004; Pulverman et al., in press), 7 months, and uses the same stimuli (Prudent et al., 2012; Pulverman & Golinkoff, 2004; Pulverman et al., 2008; Pulverman et al., in press).

To evaluate infants' ability to abstract the invariant path, we used a fixed familiarization technique in which infants were shown four exemplars of the same path across different manners for a fixed amount of time (i.e., 12 s each yielding 48 s of familiarization). This same procedure has been successfully used in Pruden et al. (2012) to show that young infants can form categories of a figure's manner of motion and has been employed by others to show that infants categorize objects and static spatial relations (e.g., Balaban & Waxman, 1997; McDonough et al., 2003; Quinn, 1994). At test, infants saw two simultaneous events: a novel exemplar from the same path category and a novel exemplar from a different path category. This fixed familiarization technique ensures that all participants have the opportunity to view the events for the same amount of time resulting in fewer infants who ''fuss out'' of the experiment.

Method

Participants

Participants included thirty 7- to 9-month-olds (M = 8.72, SD = .99; 15 males) and thirty 10- to 12-month-olds (M = 11.20, SD = .83; 15 males). Full-term infants were recruited from middle- or upper-middle-class monolingual English-speaking households in two Northeastern cities. The percentage of minority participants reflected area census information and were primarily Caucasian, with less than 5% of participants of Hispanic, Asian American, or African American descent. Twelve infants were excluded from further analyses due to fussiness (n = 4); low attention, or watching video less than 50% of the time (n = 4); side bias, calculated for all split-screen trials when attention to a side was greater than 80% (n = 2); caregiver interference, which included talking about or pointing to videos (n = 1); and experimenter error (n = 1).

Stimuli

Stimuli consisted of computer-animated events in which a purple starfish character performed an action relative to a stationary green ball in the center of the screen. In each event, the starfish performed an action composed of one of six paths (i.e., over, under, past, around, behind, and in front of) combined with one of five manners (i.e., bending, jumping jacks, spinning, toe touching, twisting; Figure 1) to yield a total set of 30 events containing a *manner* and *path* (e.g., the starfish *spinning over* [the ball], the starfish *spinning under* [the ball], etc.). The animated character and his actions were generated using Strata 3Dpro™ version 3.9 (Strata, Santa Clara, UT) and the digital movies infants viewed during the experiments were created using Final Cut Pro (Apple, Cupertino, CA).

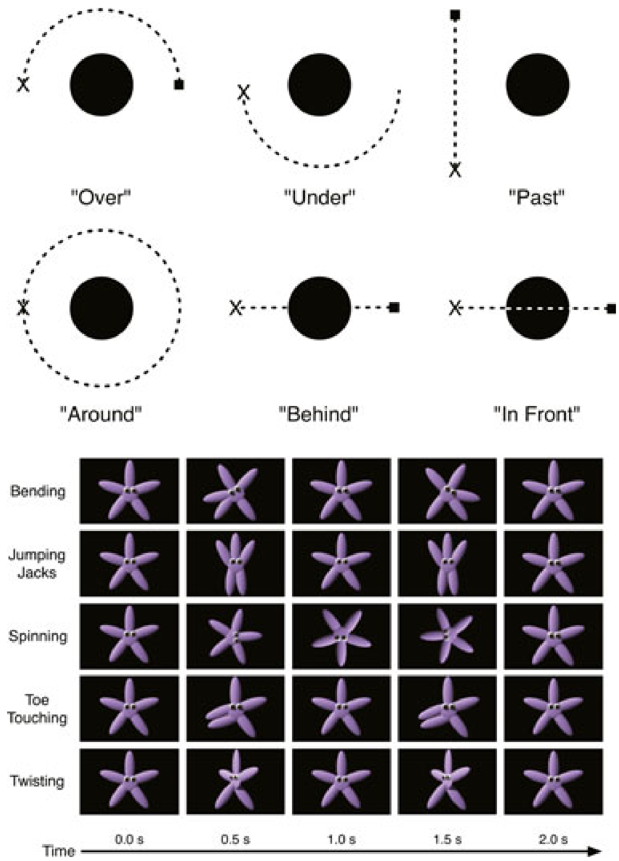

Figure 1. The X depicts the starting and ending point for each of the six paths (top figure). Each of the five manners is shown here as static pictures on a 2-s timescale, though all are presented as dynamic events (bottom figure).

Within each event, the starfish traversed its path while performing its manner over the course of 3 s, and then reversed its direction to continue back along the same path for another 3 s, and then reversed its direction twice more, for a total of 12 s. There was one exception to this timing—the *around* path was traversed over the course of 6 s and was repeated only once without changing direction, for a total of two continuous circles over 12 s. This resulted in the starfish moving at the same speed for the *around* path as for the *over* and *under* paths. Importantly, the stimuli used a back-and-forth motion for path to ensure that children made judgments based only on the dynamic stimuli of these ''via'' paths and not on the paths endpoint.

Procedure

The split-screen version of the Preferential Looking Paradigm (Golinkoff, Hirsh-Pasek, Cauley, &

Gordon, 1987; Hirsh-Pasek & Golinkoff, 1996) was used. Infants were seated on their caregiver's lap approximately 2.5 ft from a 44-in. television screen. A digital video camera placed to the left of the television screen recorded infant eye gaze during the experiment, while a digital video camera placed to the right of the television played the stimuli through the television. Caregivers were instructed to keep their eyes closed and remain silent throughout the video so that they could not inadvertently influence their child's responses.

The experiment had four phases: (a) a 12-s *introduction phase* split into two 6 s trials, (b) a 12-s *salience phase*, (c) a 48-s *familiarization phase* split into four 12-s familiarization trials, and (d) a 24-s *test phase* split into two 12-s test trials. Events in each of these four phases were presented in silence. Each trial was separated by a 3-s centering stimulus. The experiment lasted a total of 2 min 3 s. Once the caregiver and child were seated, the experimenter began recording the child's eye gaze and pressed play on the video camera containing the stimuli.

Introduction phase. Infants were shown the animated starfish, first on one side of the screen for 6 s and then on the other side of the screen for 6 s. The order of presentation was counterbalanced. During each clip, the starfish moved across the screen from left to right and back while stretching his arms and legs outward. The green ball was not present during these events. This phase ensured that infants looked to both sides of the screen.

Salience phase. The salience phase measured infants a priori preference for the events to be used later as test events. Infants viewed two side-by-side simultaneous events for 12 s. The assumption was that infants would not have a preference for either event prior to familiarization.

Familiarization phase. Each of the four 12-s familiarization trials was presented sequentially on the full television screen, with trials separated by a centering stimulus. Events from these four familiarization trials had the figure traverse the same path but varied in the figure's *manner* of motion. For example, infants participating in familiarization condition for the path category of *over* saw the starfish *spinning* over [the ball], followed by the starfish *twisting* over [the ball], the starfish *bending* over [the ball], and the starfish *jumping jacks* over [the ball].

Test phase. This phase assessed whether infants had formed a category of path across the four events that showed the figure engaging in different manners of motion along the same path. Infants were presented with two test events simultaneously on the split-screen for 12 s: (a) a familiar (in-category) test event that paired the familiarized path with a novel manner and (b) a novel (out-of-category) test event that paired a novel path with the very same novel manner. For example, infants familiarized with the category ''over'' viewed during the test phase the starfish *toe touching over* [the ball] (i.e., an in-category test event—novel manner and familiar path) and the starfish *toe touching under* [the ball] (i.e., an out-of-category test event—novel manner and novel path). The test trial was then repeated, yielding two identical 12-s test trials. Six between-subjects conditions were created. Each condition tested a different path category ($N = 5$ infants from each age group in each condition). The side of the screen on which the in-category, familiar event appeared was counterbalanced. Our prediction was that the ability to categorize the invariant path would be evidenced with a significant preference for either test event.

Centering stimulus. A 3-s video of a baby's smiling face accompanied by audio of the children's song ''Oh, Susanna'' appeared on the screen prior to each trial to ensure that infants reoriented to the center of the screen between trials.

Coding, reliability, and calculation of dependent variable. The dependent variable was infants' visual fixation time to each event. Trained research assistants, blind to the condition, coded offline recordings of infants' visual fixation to the left, right, and center of the screen for each trial. Intracoder reliability (i.e., the same research assistant coded infants' data twice) was calculated for 100% of participants, while intercoder reliability (i.e., two different research assistants) was calculated for 10% of participants. Mean intracoder reliability was $r \geq .99$ ($SD \leq .01$); the mean intercoder reliability was $r \geq .98$ ($SD \leq .01$; this was true for all experiments.)

Novelty-preference scores were calculated for each infant by taking their average looking time toward the novel event and dividing by the sum of the average looking time toward the novel event and familiar event. Proportions above .50 meant they looked longer at the novel event than the familiar event and below .50 meant they watched the familiar event longer.

Results

Prior to conducting any statistical analyses, outliers (i.e., standardized z scores ≥ 2 SD) were identified by computing the standardized z scores of the salience and test phase data. Three data points from the salience phase (two 7- to 9-month-olds and one

10- to 12-month-old) and six from the test phase (three 7- to 9-month-olds and three 10- to 12-month-olds) were outliers and thus were not included in their respective analyses. Unless otherwise noted, all statistical tests were two-tailed tests and all one-sample *t* tests were compared to a chance value of .50.

Salience Phase

A planned contrast showed no difference in performance between infants in the two age groups, $t(55) = 0.41$, $p > .05$, $d = .11$. A one-sample *t* test, collapsed across age group, revealed that infants did not show a significant preference for either the familiar event ($M = 4.55$ s, $SD = 1.83$) or novel event ($M = 3.87$ s, $SD = 1.68$) during salience ($M = .46$, $SD = .16$), $t(56) = -1.98$, $p > .05$, $d = .53$.

Familiarization Phase

A 2 (age group) × 4 (familiarization trial) repeated measures analysis of variance (ANOVA) revealed no main effect of age group, $F(1, 58) = .55$, $p > .05$, $\eta_p^2 = .01$, and no interaction between age group and familiarization trial, $F(3, 174) = 1.08$, $p > .05$, $\eta_p^2 = .02$. Thus, 7- to 9-month-olds and 10- to 12-month-olds did not differ in their attentiveness to the familiarization events. A main effect of familiarization trial in the form of a significant linear trend was found, $F(1, 58) = 6.04$, $p \le .05$, $\eta_p^2 = .09$ (see top graph, Figure 2). However, a within-subjects contrast revealed that infants' looking times during familiarization Trial 1 were not significantly different from their looking times during familiarization Trial 4, $F(1, 58) = 2.58$, $p > .05$, $\eta_p^2 = .04$, suggesting that infants were equally attentive at the beginning of familiarization (as represented by Familiarization Trial 1) as they were at the end of familiarization (as represented by Familiarization Trial 4).

Test Phase: Can Infants Categorize a Figure's Path Across Varying Manners of Motion?

No main effect of condition was found in the test phase, $F(5, 48) = 1.52$, $p > .05$, $\eta_p^2 = .14$, so all analyses collapsed across condition. A 2 (age group) × 2 (first vs. second test trial) repeated measures ANOVA evaluated age differences in the ability to form path categories across the two test trials. This analysis yielded no main effect of test trial, $F(1, 52) = .64$, $p > .05$, $\eta_p^2 = .01$, and no interaction between age group and test trial, $F(1, 52) = .38$, $p > .05$, $\eta_p^2 = .01$, the latter result justifying treating

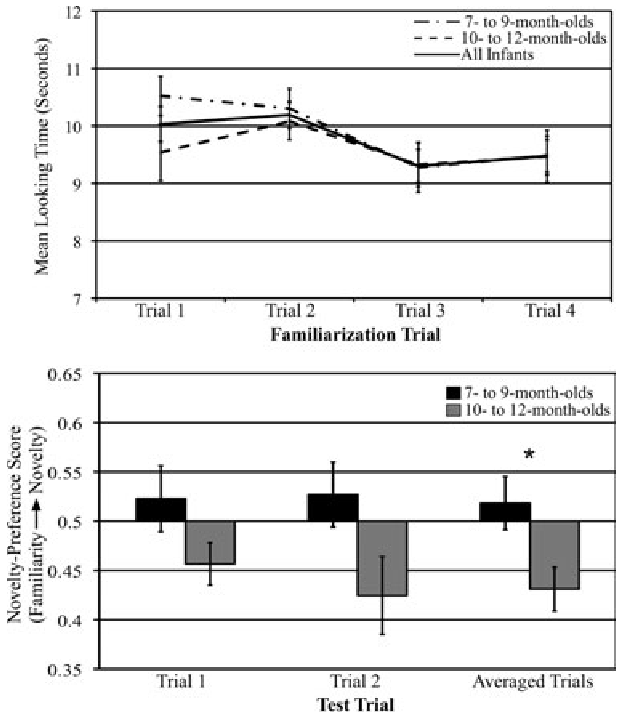

Figure 2. Despite no age difference in attention to the four familiarization events (top graph), only the 10- to 12-month-olds showed a significant preference for one of the events during the test phase, preferring to look at the familiar event (bottom graph).
*$p \le .05$.

the two test trials together in analyses. A main effect of age group, $F(1, 52) = 5.72$, $p \le .05$, $\eta_p^2 = .10$, however, indicated that younger infants were performing differently than the older infants, suggesting the two age groups should be analyzed separately.

One-sample *t* tests showed that the 7- to 9-month-olds did not show a significant preference for either the familiar, in-category event ($M = 4.11$ s, $SD = 1.59$) or the novel, out-of-category event ($M = 4.43$ s, $SD = 1.75$), during the test phase ($M = .52$, $SD = .14$), $t(26) = .67$, $p > .05$, $d = .26$. However, the 10- to 12-month-olds showed a significant preference for the *familiar,* in-category event ($M = 4.45$ s, $SD = 1.69$) over the novel, out-of-category event ($M = 3.29$ s, $SD = 1.23$) during the test phase ($M = .43$, $SD = .12$), $t(26) = -3.12$, $p \le .01$, $d = 1.22$ (see Figure 2, bottom graph).

Discussion

Experiment 1 examined when English-reared infants can categorize path across different manners. Importantly, neither age group evidenced an a priori preference for our test events prior to familiarization. Analysis of the test phase data revealed a preference only for the 10- to 12-month-olds. These infants showed a significant preference for the *familiar* path event. The fact that a significant preference emerged—even to the familiar event—demonstrates that infants could tell the difference between the new and the familiar paths, thereby showing categorization.

While many studies using a familiarization–novelty preference procedure show that infants prefer to look at novel stimuli during the test phase (Quinn & Eimas, 1986; Slater et al., 1990), there are many exceptions (e.g., Barker & Newman, 2004; Johnson & Seidl, 2009; McDonough et al., 2003; Thiessen, Hill, & Saffran, 2005; Thiessen & Saffran, 2003). Studies finding familiarity preferences have linked these preferences to various factors, including stimulus complexity, stimulus salience, task difficulty, age of participants, and amount of familiarization time (e.g., Houston-Price & Nakai, 2004; Hunter, Ames, & Koopman, 1983; Wagner & Sakovits, 1986), with some research suggesting that a familiarity preference indicates that infants have a memory of the event (Bahrick, Hernandez-Reif, & Pickens, 1997; Bahrick & Pickens, 1995; Courage & Howe, 2001). Our finding of a familiarity preference during the test phase is not a surprise in light of the familiarization phase data; a post hoc contrast revealed that infants showed no significant decrement in looking time when comparing the first familiarization trial with the last familiarization trial. Thus, infants were attentive to even the last familiarization trial and were perhaps still actively processing these stimuli. As a result, these children continued to look at the complex stimuli, leading the 10- to 12-month-olds to show a familiarity preference, rather than a novelty preference, during the test phase. Presumably, if we tested children a few months older, this test event preference would switch to a novelty preference as the task demands may be less for more experienced children. Furthermore, there exists the possibility that with additional exposure to the familiarization trials, a shift in preference, from familiarity to novelty, may also occur.

What we do know from the current study is that between 10 and 12 months of age, and prior to the time that English prepositions or verbs are being learned, infants show the ability to form a category of an invariant path over changing manners. The current findings raise the question of how these infants are succeeding in abstracting invariant paths. Are infants abstracting the *relation* of the figure's path to the ground object from our stimuli? Or are they merely abstracting the figure's trajectory, without regard to how the figure moves in relation to the ground object? We explore these questions further in Experiment 2.

Experiment 2: Does Omitting the Ground Object Disrupt Path Discrimination and Categorization?

The use of verbs and other relational terms depends on the perception of the *relation* between a figure and a ground object. It is this relation that is described in linguistics (Talmy, 1985). Prior research on infants' ability to discriminate path (Pulverman & Golinkoff, 2004; Pulverman et al., 2008; Pulverman et al., in press) and in Experiment 1, a reference object (the green ball), was always included. Experiment 2 explores whether infants are really attending to the *relation* between the figure and its movement *with respect to a ground object*.

If the construct of *path* requires an external relation between a ground object and the trajectory of a figure, removing the ground object should lessen or prevent the perception of path (e.g., ''spin over the ball'' would no longer be described as *over* without the ball). In Experiment 2, we test whether removal of the ground object prevents infants from forming a path category.

Two alternative outcomes are possible. If in Experiment 1, infants are simply using trajectory information to succeed at the task, then removing the ground object in Experiment 2 should have no effect and infants should still categorize the trajectory (path) information. In fact, removing the ball might potentially reduce the complexity of the event and perhaps make trajectory changes more compelling. On the other hand, if infants are considering the *relation* between the figure and the ground object, then removing the ground object should prevent infants from forming a category of path. We hypothesize that removal of the ground object will result in: (a) no significant preference for either event during the test phase and (b) a significant difference in performance between those 10- and 12-month-olds in Experiment 1 and children tested in Experiment 2

Method

Participants

Twenty-seven 10- to 12-month-olds (M = 11.40, SD = .99; 16 males) were tested. Four additional infants were excluded due to a side bias (n = 1) and low attention (n = 3).

Stimuli, Procedure, and Coding

The same stimuli used in Experiment 1 were used with two key changes. First, the ground object, the green ball, was removed from all events in all phases. Second, the stimuli were presented in four (as opposed to six in Experiment 1) between-subjects conditions (i.e., over, under, past, around). Six infants each participated in *over* and *past* conditions and 7 infants each participated in *under* and *around* conditions. The two conditions testing *in front of* and *behind* were not included as these conditions were identical to each other when the ground object was removed. All other aspects of Experiment 2 were the same as in Experiment 1.

Results

One data point from the salience phase and two from the test phase were found to be outliers, and thus were not included in their respective analyses.

Salience Phase

No preference for the familiar event (M = 4.72 s, SD = 1.80) or novel event (M = 4.60 s, SD = 1.32) was found prior to familiarization, (M = .50, SD = .14), $t(25)$ = .05, p > .05, d = .02.

Familiarization Phase

A repeated measures ANOVA with familiarization trial as the within-subjects variable revealed no main effects of familiarization trial, $F(3, 78)$ = 1.05, p > .05, η_p^2 = .04, and no significant linear trend in familiarization trial, $F(1, 26)$ = 2.45, p > .05, η_p^2 = .09. Thus, infants did not show a decline in looking across the familiarization trials, as indicated by the lack of a significant linear trend (see top graph, Figure 3). A within-subjects contrast revealed that infants' looking times during Familiarization Trial 1 were not significantly different from their looking times during Familiarization Trial 4, $F(1, 26)$ = 2.78, p > .05, η_p^2 = .10, suggesting that infants were equally attentive at the beginning of familiarization (as represented by Familiarization Trial 1) as they were at the end of familiarization (as represented by Familiarization Trial 4).

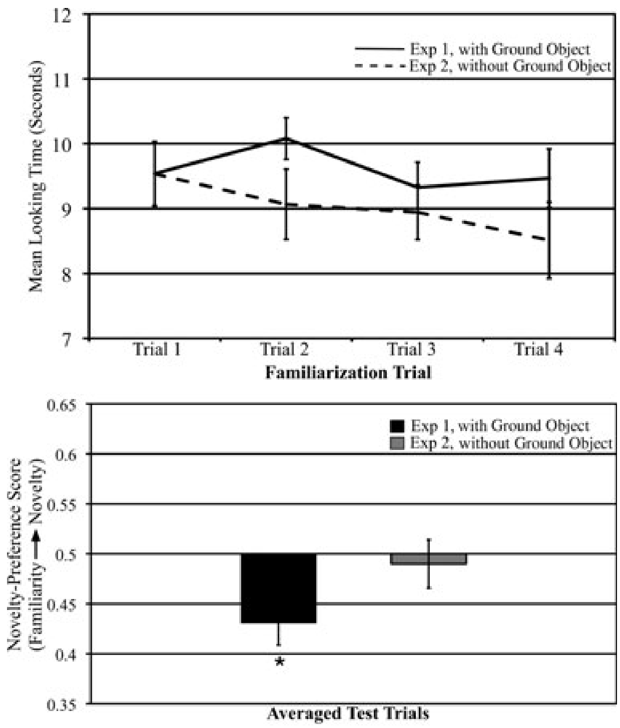

Figure 3. Ten- to 12-month-olds sustained their attention to the four familiarization events even in the absence of a ground object (top graph). When the ground object was removed, infants no longer showed a significant preference for the familiar event during the test phase (bottom graph).
*p ≤ .05.

Test Phase: Does Absence of a Ground Object Disrupt Infants' Categorization of Path?

Preliminary analysis revealed no main effect of condition on the test phase data, $F(3, 21)$ = 2.01, p > .05, η_p^2 = .22, and no main effect of test trial, $F(1, 24)$ = .01, p > .05, $\eta_p^2 \leq$ .001, so the data were collapsed across condition and test trial. A one-sample t test showed that infants did not have a significant preference for either the familiar test event (M = 4.30 s, SD = 1.60) or the novel test event (M = 4.05 s, SD = 1.24) during the test phase (M = .49, SD = .12), $t(24)$ = − .42, p > .05, d = .17. As predicted, infants in Experiment 1 looked significantly longer at the familiar event than infants in Experiment 2, $t(50)$ = − 1.80, p = .035, d = .50 (one-tailed; see Figure 3 bottom graph). In sum, infants in Experiment 1 showed evidence of abstracting the invariant path by preferring to look at the familiar test event; however, infants in Experiment 2 did not show evidence of this same ability when the ground object was omitted.

Discussion

The purpose of Experiment 2 was to examine the basis upon which infants categorized paths in Experiment 1. If infants relied on the *relation* between the figure's movement and the ground object to categorize path, then removal of the ground object should prevent infants from forming categories of path. However, if infants simply noted the different perceptual arcs (i.e., convex and concave arcs) of ''over'' and ''under,'' for example, then removing the ground object should not detract from infants' ability to categorize paths. The results suggest that the latter possibility is unlikely. Infants' ability to form a category of path appears to be contingent on the presence of a ground object. This finding suggests that infants not only attend to the dynamic figure in a scene but also the relation between the figure's path of motion and the ground object.

Experiment 2 is the first psychological examination of the linguistic definition of *path* (e.g., Talmy, 1985), indicating that the presence of an external ground object is essential to the perception and categorization of path. Our data suggest that infants are not merely relying on the perceptual similarity or dissimilarity across trajectories. Rather, 10- to 12-month-olds from Experiment 1 were likely processing the *relation* between the figure and the ground object in order to abstract and categorize path information.

Experiment 3: Do Labels Invite the Formation of Path Categories?

In Experiment 1, we found that 7- to 9-month-olds were unable to abstract and categorize path despite the fact that we know they can discriminate between path changes (Pulverman & Golinkoff, 2004; Pulverman et al., in press). Why do 7- to 9-month-olds fail in our categorization task? Seven-month-olds habituated to the same path or manner combination repeatedly (e.g., starfish flapping *over* the ball) can detect a change in a *single* aspect of the event at test (e.g., starfish flapping *under* the ball; Pulverman & Golinkoff, 2004; Pulverman et al., in press). Perhaps the diversity of the four *different* manners seen in Experiment 1 was intriguing to the 7- to 9-month-olds causing them to pay less attention to the figure's path. Might the presence of a common label spur infants into finding the common relational element in the events? If it does, they might now notice the path that is common to all the different events.

In Experiment 3, we take up the question of whether the addition of language to our task aids infants' categorization of path and ask whether a common label can facilitate the categorization of an invariant path in 7- to 9-month-olds. The fact that 10- to 12-month-olds exhibited a familiarity (and not a novelty) preference in Experiment 1 suggests that the formation of path categories is a difficult task. This raises the question of whether younger infants might also form path categories if offered additional help. For example, language might promote attention to the invariant path of the stimulus events. Indeed, language has spurred the formation of both object and spatial categories in other studies (Balaban & Waxman, 1997; Baldwin & Markman, 1989; Booth & Waxman, 2002; Casasola, 2005; Casasola, Bhagwat, & Burke, 2009; Casasola & Cohen, 2002; Gentner & Loewenstein, 2002; Gopnik & Nazzi, 2003; Loewenstein & Gentner, 2005; Namy & Gentner, 2002; Waxman & Markow, 1995). Some speculate that labeling is one particularly powerful mechanism that can help children observe deeper relational structures (Gentner, 2003; Gentner & Loewenstein, 2002; Waxman, 2003). Experiment 3 examines whether language helps the youngest group succeed in forming categories of path.

Two predictions are offered. First, we predicted that a novel label would heighten attention to the events presented during familiarization. Thus, infants participating in Experiment 3 should show an increase in attention during the familiarization trials when compared to those infants who did not hear a label in Experiment 1. Second, we predicted that the addition of a novel label during familiarization would facilitate the categorization of the invariant path. We expected infants to show a significant preference for one of the events during the test phase.

Method

Participants

Twenty-four 7- to 9-month-olds ($M = 8.50$, $SD = .77$; 12 males) were tested. Four additional infants were excluded for fussiness ($n = 1$), low attention ($n = 2$), and side bias ($n = 1$).

Stimuli, Procedure, and Coding

Linguistic stimuli accompanied the events only during the familiarization phase. A novel label by itself, ''javing,'' was produced in infant-directed speech by a female. We make no claim about whether this label was interpreted as a noun or a verb. The procedure was identical to Experiment 1, with the exception of the familiarization phase. Infants were shown four different 12-s events, each depicting the starfish performing the same path with four distinct manners. Infants heard the novel label repeated 16 times, four times during each familiarization trial. The test phase was presented in silence as in Experiment 1.

Results

Two data points from the salience phase and one from the test phase were outliers, and thus were not included in their respective analyses.

Salience Phase

No preference was found for either the familiar event (*M* = 4.17 s, *SD* = 1.70) or novel event (*M* = 4.68 s, *SD* = 1.95) prior to familiarization, (*M* = .52, *SD* = .16), $t(21) = .67$, $p > .05$, $d = .29$.

Familiarization Phase

A repeated measures ANOVA with familiarization trial as the within-subjects variable revealed no main effects of familiarization trial, $F(3, 69) = 1.66$, $p > .05$, $\eta_p^2 = .07$, and no significant linear trend in familiarization trial, $F(1, 23) = 1.23$, $p > .05$, $\eta_p^2 = .05$. Infants did not show a decline in looking across the familiarization trials (see top graph, Figure 4). To test our prediction that labels would heighten attention to the familiarization events, we compared the average looking times during familiarization in Experiment 3 (i.e., infants who heard label) with the average looking times of the 7- to 9-month-olds during familiarization in Experiment 1 (i.e., infants who did not hear label). A repeated measures ANOVA with study (7- to 9-month-olds in Experiment 1; infants in Experiment 3) as a between-subjects factor and familiarization trial as a within-subjects factor revealed a significant main effect of familiarization trial, $F(3, 156) = 2.29$, $p \le .05$, $\eta_p^2 = .04$, and a significant familiarization Trial × Study interaction, $F(3, 156) = 4.17$, $p \le .05$, $\eta_p^2 = .07$. During the third familiarization trial, infants in Experiment 3 (*M* = 10.49 s, *SD* = 1.51) looked significantly longer at the event than infants in Experiment 1 (*M* = 9.28 s, *SD* = 2.37), $t(52) = 2.17$, $p \le .05$, $d = .61$. In the last familiarization trial, infants in Experiment 3 (*M* = 10.59 s, *SD* = 1.60) looked significantly longer at the event than infants in Experiment 1 (*M* = 9.49 s, *SD* = 1.85), $t(52) = 2.31$, $p \le .05$, $d = .64$. No significant differences were found between infants' looking times for the first two familiarization trials (*p*s > .27). While infants in Experiment 1 were starting to show a decrease in attention to the events, infants in Experiment 3, who heard a label, sustained their attention to the events.

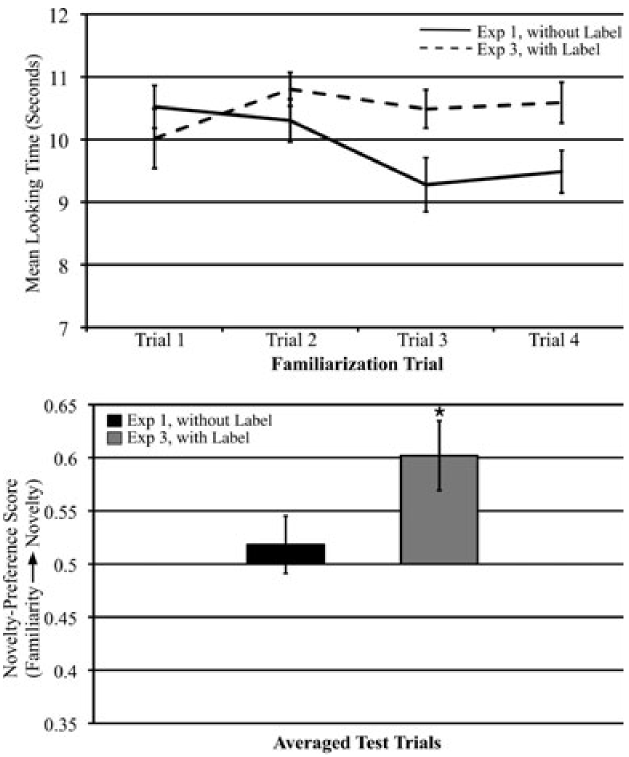

Figure 4. Seven- to 9-month-olds showed sustained attention to the events when they heard a label during the familiarization phase (top graph) and a significant preference for the novel event at test. Their novelty-preference scores were significantly different from those infants who did not hear a label in Experiment 1 (bottom graph).
*$p \le .05$.

Test Phase: Does a Common Label Help Infants' Form Categories of Path?

No main effects of condition, $F(5, 17) = 1.96$, $p > .05$, $\eta_p^2 = .37$, or test trial, $F(1, 22) = .86$, $p > .05$, $\eta_p^2 = .04$, were found, so further analyses collapsed across these variables. A one-sample *t* test showed that infants had a significant preference for the novel test event (*M* = 4.68 s, *SD* = 1.99) over familiar test event (*M* = 3.05 s, *SD* = 1.53) during the test phase (*M* = .60, *SD* = .16), $t(22) = 3.12$, $p \le .05$, $d = 1.33$. As predicted, infants given a label in Experiment 3 showed a significant preference, in this case for the novel event, when compared directly to 7- to 9-month-olds in Experiment 1 ($M = .52$, $SD = .14$), $t(48) = 2.00$, $p \leq .05$, $d = .56$ (Figure 4, bottom graph).

Discussion

Experiment 3 was designed to test whether a label presented in the familiarization phase aids 7- to 9-month-old infants' categorization of path. We predicted that infants hearing a label during familiarization would show heightened attention to the familiarization events relative to those infants participating in Experiment 1. As predicted, our results suggest that the addition of the label did help infants sustain their attention to the familiarization events, in this case the last two events during the familiarization phase. We also predicted that the addition of a label would promote infants' categorization of the invariant path such that they would now be able to note the relational information across the series of events. Indeed, infants provided with a label during familiarization not only showed a significant preference for the *novel event* during the test phase but also significantly differed in their performance when compared to their Experiment 1 counterparts, suggesting that a common label helps infants form categories of path.

What is the mechanism by which labels help infants in this task? Two mechanisms are proposed: labels as attention getters and labels as category markers. Our results show that the introduction of the label sustains attention to the familiarization events, with infants looking longer at the last two familiarization events than those infants not hearing the label (Experiment 1). Labels also appear to be a powerful mechanism by which infants are able to form new categories of both objects (e.g., Baldwin & Markman, 1989; Booth & Waxman, 2002; Namy & Gentner, 2002) and spatial relations (e.g., Casasola et al., 2009; Loewenstein & Gentner, 2005). That is, labels denote category membership and inform children of when objects and events are of the same kind (Gelman, 2003). While infants now formed a path category, it is unclear whether the labels were merely promoting attention to the familiarization events, marking category membership, or both. Thus, future research will need to address whether infants are using the label to actually mark path category membership or whether labels simply led to increased exposure to the familiarization events and ultimately success on the task. More sophisticated measures, such as eye tracking, may be helpful in determining whether infants are actually tracking the figure's path when a label is presented. Further, if labels are merely acting as attention getters, then presumably any type of auditory stimulus, including a musical tone or melody, should also show the same effect as a label. Research on object categorization offers mixed results with studies showing that musical tones do not elicit the same effects as labels (Balaban & Waxman, 1997; Fulkerson & Haaf, 2003; Fulkerson & Waxman, 2007; Woodward & Hoyne, 1999), while others show that nonlinguistic auditory stimuli can facilitate categorization (Roberts & Jacob, 1991). Future work will need to examine the role of other linguistic or perceptual stimuli in the categorization of events. For example, aid may come in the form of additional exposure time to the familiarization events. What is clear from our results is that a common label facilitates the categorization of path. When given proper support, younger infants can form categories of events that are important for later lexical acquisition.

General Discussion

The present studies provide the first evidence that infants can form categories of *paths when witnessing dynamic events*. Infants demonstrate the ability to isolate and abstract the invariant path even when other features of the display are changing. In Experiment 1, we found that 10- to 12-month-olds could categorize path across varying manners, while infants younger than 10 months failed to show evidence of this ability. When we omitted the ground object in Experiment 2, we found that 10- to 12-month-olds were no longer able to form a category of path. Finally, in Experiment 3, we saw that a label not only promoted 7- to 9-month-olds' attention to the familiarization events but also helped them form a category of path perhaps by helping them notice the similarities across events. In fact, these young infants showed a *novelty preference* during the test phase after hearing a label during the familiarization phase, suggesting that they had fully processed these familiarization events (unlike the 10- to 12-month-old infants in Experiment 1). These results indicate that by 10–12 months, infants are categorizing path using relational information and can do so even younger if provided with an aid.

The current studies, in conjunction with those investigating other semantic components, like containment and support (Casasola, 2005; Casasola & Cohen, 2002; Choi, McDonough, Bowerman, & Mandler, 1999), sources and goals (Lakusta, Wagner, O'Hearn, & Landau, 2007), manner of motion (Pruden et al., 2012), and figures and grounds (Göksun et al., 2010), are among the first to shed light on when and how infants can discriminate and categorize spatial relations that are codified in relational terms. Our studies showed that infants could form categories using dynamic path information rather than simply using the static endpoints of an event. Further, the present studies are the first to look at a semantic component lexicalized primarily in English spatial prepositions. This is in contrast to previously published work that reports on infants' ability to discriminate and categorize components conflated in English motion verbs (Pruden et al., 2012).

Results from the present studies and from previous research (Casasola, 2005; Casasola & Cohen, 2002; Choi et al., 1999; Pruden et al., 2012; Pulverman et al., 2008; Pulverman et al., in press) force us to reconsider why verbs and other relational terms seem so difficult to learn relative to nouns. The impetus for these studies came from Golinkoff et al.'s (2002) suggestion that verb learning requires three important steps: (a) paying attention to actions and relations, (b) forming categories of actions and relations, and finally (c) mapping words onto these actions and relations. The first step—the ability to individuate actions—was shown by Wynn (1996) and Sharon and Wynn (1998) who found that 6-month-old infants could distinguish between separate instances of jumping and falling. A number of studies have addressed the third step—children's ability to map actions and relations to the verbs and prepositions of their language. As Snedeker and Gleitman (2004), Imai et al. (2008), and Maguire, Hirsh-Pasek, Golinkoff, and Brandone (2008) show, mapping is not simple and often requires multiple exposures to a verb–action combination. This article addresses the second step: when and how infants form categories of actions encoded in relational terms. As researchers have become more attuned to the fact that a comprehensive theory of word learning must account for all word classes, researchers have begun to explore the knowledge needed to map words onto spatial relations. The body of evidence presented here suggests that preverbal infants *are* sophisticated observers of actions who categorize one of the semantic components, *path*, encoded in English relational terms. Infants appear to have at least some of the conceptual knowledge needed to learn relational terms.

Future work will need to examine when infants can move beyond abstracting path as a perceptual invariant as categorization is much richer than detecting spatial invariants from a scene. Indeed, ongoing research suggests that infants can discriminate between different manners performed by human actors (Song, 2009) and form categories of paths when they view *different* animated characters performing the same action (Pruden, 2007). We also need to explore languages other than English. When and how do children learning different languages abstract the finite list of conceptual components that are encoded in all languages (Langacker, 1987; Talmy, 1985), and how does ambient language influence attention to these components in events? As we begin to understand how young children process actions and spatial relations, we can begin to ask how they might come to package these actions and relations for use in language. The studies presented here are among only a few to show that infants have the ability to categorize a key semantic component—path—in dynamic motion events. Abstracting the invariant path is an important first step in understanding how infants ''package'' actions across events into language-specific semantic components that will be later encoded in language.

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