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# Carving categories in a continuous world:

# Preverbal infants discriminate categorical changes before distance changes in dynamic events

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Abstract

To learn motion verbs and prepositions, children must categorize event components such that *jumping 1 meter over the puddle* and *jumping 3 meters over the puddle* are both instances of *jumping*. Thus, children's categories must allow variability in coordinate properties, while preserving the relational component labeled by motion verbs and prepositions. The current study asks if preverbal infants notice within-category distance changes (e.g., height of a jump) more than across-category distance changes, (e.g., *over* versus *under*). Results suggest that categorical changes are most important, which has implications for how children carve a continuous world into categories that coincide with language.

# Carving categories in a continuous world:

## Preverbal infants discriminate categorical changes before distance changes

Imagine a child jumping over a puddle. At what point did the child start jumping and when did jumping end? Is it still *over* when the child jumps *ten centimeters over* the puddle or *one meter over* the puddle? Our world is composed of continuous events that unfold in time and space. To describe these same events however, we use language, a categorical system that imposes boundaries on otherwise fluid events.

Verbs, particularly motion verbs, and prepositions express relational meaning. This point of view has been described by linguists (Talmy, 1985, 2000; Jackendoff, 1983) and tested by psychologists (e.g., Bowerman, 1996; Cifuentes-Ferez & Gentner, 2006; Gentner, 1978; Gentner & Boroditsky, 2001; Gentner & Bowerman, 2009). In order to learn motion verbs and prepositions, children must detect metric and categorical changes in dynamic events. Although infants readily process metric information (e.g., Duffy, Huttenlocher, Levine & Duffy, 2005; Huttenlocher, Duffy & Levine, 2002; Newcombe & Huttenlocher, 2006; Newcombe, Huttenlocher & Learmonth, 1999) and categorical information (e.g., Göksun, Hirsh-Pasek & Golinkoff, 2009; Lakusta, Wagner, O'Hern & Landau, 2007; Pruden, Hirsh-Pasek, Maguire, & Meyer, 2004; Pulverman, Golinkoff, Hirsh-Pasek, & Buresh, 2008), they must represent both coordinate and categorical information within a single dynamic event to express relationships in language. In fact, the challenge of translating continuous spatial information into the categorical units of language might account for some of the difficulty children have in learning spatial language (Gentner & Boroditsky, 2001; Golinkoff & Hirsh-Pasek, 2008). This paper is the first to examine whether preverbal infants process both continuous information (distance - how far an object moves) and categorical information (over, under - where an object moves) in a dynamic display. It also asks whether one type of information is privileged over another.

*Encoding spatial relations*

The conjecture that humans jointly represent continuous and categorical information resulted in dual-system models for encoding spatial relations between objects or parts of objects (Huttenlocher, Hedges & Duncan, 1991; Kosslyn, 1987, 2006; Martin, Houssemand, Schiltz, Burnod, & Alexandre, 2008). *Coordinate spatial relations* refer to the exact spatial locations that are expressed in metric units, such as *the car is located* ***10 meters*** *away from the house*. *Categorical spatial relations* denote spatial positions relative to a referent, such as *the car is on the* ***left*** *of the house*. Here, *left* captures the abstract relation between the car and the house without specifying exactly where the car is in relation to the house. This represents a coarser encoding than specifying that the car is 10 meters from the left of the house. Neurological evidence for the coordinate-categorical distinction indicates that coordinate and categorical spatial relations are differentially mapped in the brain. Neuroimaging studies and research with brain-damaged individuals show that the left hemisphere is better than the right hemisphere in encoding categorical spatial relations whereas the right hemisphere is found to be better for coordinate spatial relations (e.g., Kosslyn, 2006; Kosslyn, Thompson, Gitelman, & Alpert, 1998; Laeng, 1994; Laeng, Chabris, & Kosslyn, 2003; but see Martin et al., 2008).

Encoding spatial relations into both coordinate and categorical information also has practical implications. Coordinate cues may be particularly critical for skills such as navigation, where the distance you walk before turning left determines whether or not you reach home.

Alternatively, categorical cues are necessary for language, which describes groups of similar spatial relations like *over the bridge* or *under the table*. Behavioral data support this division, providing evidence of a mismatch between adults' encoding of spatial location, depending on the method of recall (Crawford, Regier, & Huttenlocher, 2000; but see Hayward & Tarr, 1995). Crawford and colleagues briefly showed participants a dot within a circle and then asked them to recall its location both linguistically and non-linguistically. They found that linguistic judgments of spatial location were biased toward the vertical axis of the circle, with adults using terms like *above* and *below*. In contrast, non-linguistic judgments erred toward the center of each quadrant of the circle (i.e., toward the diagonals). The authors conclude that linguistic representations of space are different than non-linguistic representations of space, perhaps because language does not afford an easy way to describe a location *above and 10 centimeters to the right*. Although many factors have been shown to influence the comprehension of spatial relations (Carlson-Radvansky & Irwin, 1993; Coventry, Prat-Sala, & Richards, 2001; Hayward & Tarr, 1995), it seems that when continuous space is described categorically by spatial language, people process less detail in their spatial relations (Landau & Jackendoff, 1993; see also Halstead & Forbus, 2007).

*Infants detect coordinate and categorical information*

Even prelinguistic infants are able to notice both coordinate and categorical information as they vary separately in events. Research suggests that as early as 6 months of age, infants encode, or perceive coordinate spatial relations such as an object's extent (Duffy et al., 2005; Huttenlocher et al., 2002), quantities that vary in amount (Mix, Huttenlocher, & Levine, 2002), and an object's height in occlusion and containment events (Baillargeon & Graber, 1987; Hespos & Baillargeon, 2001). Newcombe, Huttenlocher, and Learmonth (1999), for example, demonstrated that 5-month-old infants were able to discriminate the location of a hidden object in a sandbox when it was located 20 centimeters or 30 centimeters away from the original location. These findings suggest that infants encode location, or metric information, in continuous space (see Wang & Baillargeon, 2006 for a discussion of encoding events in infancy).

Within the last decade, research has also made progress in how preverbal infants abstract components of events that are codified in spatial language (e.g., Göksun et al., 2009; Lakusta et al., 2007; Pruden et al., 2004; Pulverman et al., 2008). These relational components are categorical in nature rather than coordinate. Dynamic events are composed of various semantic components such as *figure* (the agent of the action), *path* (the trajectory of the motion), *manner* (how an action is performed), *ground* (the reference point), *source* (the starting point), and *goal* (the endpoint) (Jackendoff, 1983; Talmy, 1985). To learn motion verbs and spatial prepositions, children must initially discriminate and abstract these event components (e.g., Gentner, 1982; Gentner & Boroditsky, 2001; Golinkoff, Chung, Hirsh-Pasek, Liu, Bertenthal, Brand, et al., 2002). For example, by 13 months of age, infants notice both when a figure changes and when a ground changes in a dynamic crossing event (Göksun et al., 2009). Infants also increase attention to both path and manner changes in a dynamic scene, such that *twisting over* a ball is treated differently than *twisting under* a ball or *spinning over* a ball (Pulverman et al., 2008). Ten-month-olds also demonstrate an ability to form a category of path (e.g., *over*) across varying exemplars of manner (e.g., *spinning* ***over***, *twisting* ***over***, *bending* ***over***, and *jumping jacks* ***over***) (Pruden et al., 2004).

Group data on children's ability to discriminate and categorize dynamic event components regularly shows large variability in infant task performance (e.g., Göksun et al., 2009; Pruden et al., 2004; Pulverman et al., 2008). Recent analyses suggest that these individual differences in children's ability to form these categories predict their performance on spatial language tasks at 36 months of age, but do not predict success on other non-linguistic cognitive tasks (Roseberry, Göksun, Hirsh-Pasek, Newcombe, Golinkoff, Novack, et al., 2009). In this case, group data indicates that infants are adept at noting the event components encoded in spatial terms and analyses of individual differences connect these abilities with later spatial language acquisition.

*Combining coordinate and categorical cues*

Although research offers a multitude of evidence that infants are capable of encoding events into both coordinate (Duffy et al., 2005; Huttenlocher et al., 2002) and categorical (Quinn, 2007) information prior to learning language, each of these tasks presented events in which *only* coordinate or categorical information varied. Spatial terms, however, map onto events that vary in both coordinate and categorical information. To date, only one study has investigated infants' ability to encode spatial cues in the context of changing coordinate and categorical cues. In a series of experiments, Quinn (1994) examined 3- to 4-month-olds' categorical representations of the static spatial relations *above* and *below*. Infants were familiarized with a dot located in different positions *above* a horizontal reference bar. At test, they were presented with a dot in a novel location *above* the bar and with a dot in a novel location *below* the bar. In each test trial, the novel location of the dot was equidistant from the location of the familiarized locations, providing a constant change in coordinate information, but only one test trial demonstrated a new category relationship between the dot and the bar. Infants looked longer to the novel category at test, suggesting not only that infants formed categories of the spatial relations *above* and *below*, but also that infants preferred categorical cues when both coordinate and categorical information varied. Importantly, infants did not categorize these spatial relations without the horizontal reference bar (see also Quinn, Cummins, Kase, Martin, & Weissman, 1996; Quinn, Polly, Furer, Dobson, & Narter, 2002).

This work begins to explore the trade-offs between continuous and categorical representational systems. Yet spatial language not only maps onto static relations but also onto dynamic events. In fact, the actions described by motion verbs are both relational and dynamic by definition (Bowerman, 1996; Cifuentes-Ferez & Gentner, 2006; Gentner, 1978; Gentner & Boroditsky, 2001; Gentner & Bowerman, 2009). To learn verbs, children must uncover coordinate and categorical information as they unfold in time. Children around the world might start with similar prelinguistic concepts that are gradually refined and tuned in to the expressions their native language emphasizes. As language meets dynamic and temporal events, it may dampen attention to some information and heighten sensitivity to others (Göksun, Hirsh-Pasek, & Golinkoff, 2010).

Despite Quinn's promising results on infants' ability to process complex coordinate and categorical spatial relations in static displays, research has not explored whether infants preferentially encode *either* coordinate or categorical information in dynamic displays.

The current study takes the first step toward understanding this question. Do preverbal infants discriminate all changes in coordinate information, or are changes in categorical relationships privileged? Using looking time as a dependent measure, we ask whether infants treat *moving 5 centimeters* ***over*** *a ball* as an event in the same category as *moving 15 centimeters* ***over*** *a ball*, but *moving 5 centimeters* ***under*** *a ball* (an equivalent distance change with a new spatial relation) as an event in a different category. If infants attend to categorical changes, then they should distinguish relational changes such that all instances of the relation *over* are considered different from an instance of the relation *under* (i.e., across-category). This strategy is conducive to language development because it signals that infants are selectively noting changes that will be encoded in language (changes in category) and not changes that are not as readily encoded in language (changes in distance). In contrast, if infants attend only to coordinate information, they will equally differentiate both of these distance changes, regardless of whether the categorical relationship between the two objects has changed (i.e., across-category and within-category).

## Method

### *Participants*

Thirty-six monolingual, English-reared infants (20 female) were recruited between the ages of 7 and 9 months (M = 8.42, SD = .67, range = 7.03-9.63). All infants were full-term. An additional 34 children were excluded from the final sample for failure to reach the habituation criterion (22), bilingualism (5), fussiness, or an inability to watch the video due to crying (4), prematurity (2), and experimenter error (1). This discard rate is typical for habituation studies (e.g., Casasola, Cohen & Chiarello, 2003; Cashon & Cohen, 2000; Cohen & Oakes, 1993; Pulverman et al., 2008; Schlottmann et al., 2009) and a recent meta-analysis finds no relationship between experimental outcome and infant attrition in habituation paradigms (Slaughter & Suddendorf, 2006). Children in the final sample were predominantly White and from middle-class neighborhoods in suburban Philadelphia (US Census Bureau, 2000).

### *Stimuli*

The stimuli were computer-animated events consisting of an animated purple starfish, Starry, moving around a green ball that was fixed in the center of the screen (Pulverman et al., 2008). The green ball was included to provide a reference point by which infants could distinguish the *over* and *under* paths (Talmy, 1985). All of the events featured Starry moving in a straight line at different distances *over* or *under* the ball. Starry's movement along the paths was continuous and repetitious, such that he moved to the right for 3 seconds, and then traversed the same path in reverse for 3 seconds. The back-and-forth path focused infant attention on the movement, as opposed to the beginning or end points of the path (e.g., Pulverman et al., 2008). Although previous studies of path have shown characters traveling in an arced path over or under the ball (Pruden et al., 2004; Pulverman et al., 2008), the current study used straight line paths to ensure that trajectory information was not available to distinguish *over* from *under*. In all events, Starry flapped his arms as he moved to maintain children's interest. Starry's manner of motion was repetitive, continuous, slow (i.e., 1 arm flap per second) and identical throughout the experiment. Previous research has shown that infants are able to discriminate paths of motion across a constant manner of motion (Pulverman et al., 2008). No language accompanied the stimuli.

*Procedure*

An infant-controlled habituation procedure was used to determine whether infants distinguished all distance changes or only those that resulted in a new relational category. Infants were seated on their parent's lap in front of a 50.8-centimeter television monitor. A video camera positioned above the television was connected to a second television monitor behind a partition to provide live video of the infants' behavior during the study (see Figure 1). From behind the partition, an experimenter observed the infants on the monitor and administered the experiment from a computer with Habit 2000 software (Cohen, Atkinson & Chaput, 2000). This experimenter recorded infants' visual fixation on a keyboard during the experiment. Fixations were coded by pressing a button while the infant was looking at the video screen and releasing the button when the infant looked away. Online coding is essential to an infant-controlled paradigm as the progression of the experiment depends on each infant's particular looking patterns. Additionally, the experimenter was blind to the experiment phase and stimuli. That is, they could not see the stimuli on the infants' screen and the coding computer did not display phase information (i.e., habituation, test, recovery) during the experiment.

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INSERT FIGURE 1 HERE

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Infants were habituated to Starry traveling at a constant distance either *over* (+5 centimeters) or *under* (-5 centimeters) the central ball. Half of the infants saw only *over* trials during habituation and half of the infants only saw *under* trials during habituation. A child was considered to have habituated to the stimuli when their looking time during three successive trials (e.g., trials 4-6) were at or below 50% of their initial looking time, as established during the first three habituation trials (trials 1-3). Because this paradigm was infant-controlled, the total length of the experiment varied by child, but each child proceeded to the test phase only after a 50% decrement in looking time. Infants were given a maximum of 15 trials to habituate to the stimuli. If habituation criterion was not reached after trial 15, the experiment was stopped and the child's data was discarded for failure to reach the habituation criterion.

Once an infant habituated to the stimuli, they viewed 3 counterbalanced test trials. A *control trial* presented the exact stimuli seen during habituation (either *over +5 centimeters* or *under -5 centimeters*, depending on the habituation stimulus). Two change test trials showed a uniform distance change in opposing directions (+10 centimeters, -10 centimeters). In the *within-category trial*, Starry moved at a new location, but in the same category relative to the ball as seen during habituation. In the *across-category trial*, Starry traveled in a new location that was also in a new semantic category relative to the ball (see Figure 2). For example, an infant who was habituated to Starry traveling *over* the ball (+5 centimeters) would see Starry move +15 centimeters *over* the ball for the within-category trial and -5 centimeters *under* the ball for the across-category trial. Note that the stimuli in both test trials are novel to the infant. In contrast, infants who were habituated to Starry moving under the ball (-5 centimeters) would see Starry traveling -15 centimeters *under* the ball for the within-category trial and +5 centimeters *over* the ball for the across-category trial. Thus, although the absolute distance change remained the same in both test trials (+/-10 centimeters), only one distance change placed Starry in a different relational category. If infants are sensitive to distance changes, then infants should dishabituate to both test trials, regardless of the relationship between Starry and the central ball. If infants preferentially attend to categorical distinctions that will be important to language acquisition, then they should only dishabituate to the across-category test trial, as this is the only test trial that shows an infant a novel relationship between the starfish and the ball.

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Finally, after all 3 test trials (control, within-category, across-category), a recovery trial showed infants a video of a laughing baby to ensure that participants would dishabituate to a novel, engaging stimulus. The recovery trial provided evidence that infants were not simply too fatigued by the end of the experiment to look at any video display. Indeed, all infants looked longer to the recovery trial than to each of the test trials.

All trials in each phase (habituation, test, recovery) played until the infant looked away for 2 consecutive seconds, or for a maximum of 30 seconds. An attention-getter flashed on the screen between trials and played a song until infants resumed looking at the screen.

*Reliability*

Coders were trained to establish at least 97.5% reliability with experienced coders before they were permitted to serve as the experimenter for the current study. To establish intra-rater reliability, each coder performed secondary offline coding for 20% of the videotapes for which they served as the experimenter. Intra-rater reliability was above 99% (M = 99.2%, SD = .01). Additionally, 20% of the participants' videotapes (7 infants) were re-coded offline by a second coder to ensure inter-rater reliability. Second coded videotapes were at least 97.5% reliable with the first coder (M = 98.3%, SD = .04).

## Results

To examine infants' looking times during the test phase relative to the particular test events they saw, a 2 (Stimuli Set A, *over* vs. Stimuli Set B, *under*) X 3 (control test, within-category test, across-category test) mixed-design ANOVA was calculated. Results revealed a main effect of test trial, $F(2, 68) = 8.5$, $p < .001$, but no main effect of stimuli and no interaction. Paired-samples *t*-tests were used to compare looking time during each change test trials to the control trial, and to compare the two change trials. Significance criteria were adjusted (.0167) according to Bonferroni corrections for multiple comparisons. Infants looked longer to the *across-category* test trial than to the *within-category* test-trial, $t(35) = 3.29$, $p < .01$. Looking time to the *across-category* test trial was marginally greater than looking time to the control test trial, $t(35) = 2.43$, $p = .02$, whereas looking time to the *within-category* test trial did not differ from the control test trial, $p > .05$ (see Figure 3). That is, infants noticed only relational changes in dynamic scenes.

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Although significant, the high variability in these results suggests that potentially interesting individual differences might exist within the data. One difference that commonly emerges in an infant-controlled habituation paradigm is the time it takes children to habituate to a particular stimulus (Baillargeon, 1987; Bornstein, 1985; Colombo, Shaddy, Richman, Maikranz & Blaga, 2004; DeLoache, 1976; Frick, Colombo & Saxon, 1999; Johnson, Bremner, Slater & Mason, 2000; Miller, Ryan, Short, Ries, McGuire & Culler, 1977; Samuelson & Smith, 1998; Schöner & Thelen, 2006; Wolfe & Bell, 2004). Recall that habituation designs are predicated on the idea that a child advances to the test phase as soon as they have fully processed, or habituated to, a particular stimulus (e.g., Cohen, 2004). Previous research has linked time-to-habituation with general cognitive abilities, suggesting that children who spend less time in the habituation phase are more efficient processors, requiring less time to process a given stimulus than children who spend more time in the habituation phase (Bornstein, 1989; DeLoache, 1976; Frick et al., 1999; Miller et al., 1977; Schöner & Thelen, 2006; Tamis-LeMonda & Bornstein, 1989). Thus, infant looking time during habituation was examined as an explanatory source of individual differences.

In the current study, infants spent, on average, 54.87 seconds (range = 16.9 – 113.7, SD = 23.22) and 7 habituation trials (range = 4 – 13, SD = 2.85) to reach the criterion of 50% decrement in looking time and proceed to the test phase of the experiment. To reveal possible differences among infants' discrimination between test trials as a result of their looking time during habituation, Pearson correlations were computed between each of the three test trials and the amount of time infants spent habituating to the dynamic stimulus. We chose to use total looking time during habituation as the operative measure of habituation efficiency because it is a continuous measure that provides variability and has been widely used in the literature (e.g., Baillargeon, 1987; Johnson et al., 2000). Results indicated that infants' total looking time during habituation (e.g., Baillargeon, 1987; Johnson et al., 2000) was significantly correlated with looking to the *within-category* test, $r = .478$, $p < .01$. Total looking time during habituation was not significantly related to infant looking time during the *across-category* trials, $r = .149$, $p > .05$, or to looking time during the control trial, $r = .257$, $p > .05$. Thus, the longer infants spent in habituation, and the longer they were exposed to the habituation stimulus, the longer they looked in the *within-category* trial.

The relationship between measures of looking during habituation and discrimination of the coordinate and categorical changes was further probed by performing a median split on the data based on the infants' total looking time during habituation. A mixed-design ANOVA was used to evaluate the effect of looking time during habituation (fast habituators and slow habituators) on test trials (*control* test, *within-category* test, *across-category* test). A main effect of test trial emerged, $F(2, 68) = 7.169$, $p < .001$ as well as a significant interaction between test trial and habituation time $F(2, 68) = 5.142$, $p < .01$. Post-hoc comparisons examined the change test trials (*within-category* test, *across-category* test) relative to the control test trial for the fast habituators (N=18) and slow habituators (N=18). With Bonferroni adjustments applied (.0125), these comparisons revealed that both fast and slow habituators significantly discriminated the *across-category* test, $t\ (17) = 3.477$, $p < .01$, and $t\ (17) = 3.234$, $p < .01$, respectively. In contrast, fast habituators showed marginal discrimination of the *within-category* test, $t$ (17) = 2.719, $p$ = .015, while slow habituators did not, $t$ (17) = .928, $p > .05$.

Discussion

The current study is the first to investigate how infants encode dynamic events given variation in both coordinate and categorical spatial information. Specifically, we asked whether infants would attend to changes in an event's coordinate information, or whether the coordinate information only became relevant if it resulted in a new category. Results indicated that infants privilege categorical information over changes in the coordinate spatial information. This preference is conducive to preverbal infants' impending language development as these are the spatial changes that are most readily encoded in languages. Interestingly, although efficient processing was linked to infants' ability to distinguish changes in coordinate information in the form of a reliable correlation between total looking time at habituation and looking time for within-category trials, categorical changes nevertheless emerge as the clear preference for preverbal infants. This may be due to the fact that they provide a coarser coding of the available data in space.

These findings are consistent with prior research suggesting that infants are able to note categorical information (Pruden et al., 2004; Pulverman et al., 2008). As in these studies, we find evidence that infants can form categories of dynamic spatial relationships such as *over* and *under*. Yet, the current results are a departure from previous research that suggests infants also discriminate coordinate information (Duffy et al., 2005; Huttenlocher et al., 2002; Newcombe et al., 1999), perhaps because our stimuli varied both coordinate and categorical cues in a dynamic event. The current study furthers the literature in several ways.

First, this study begins the investigation of how preverbal infants evaluate the relative importance of coordinate and categorical spatial information as seen in dynamic events. By presenting categorical changes in a dynamic event while controlling for changes in coordinate information, we can tell whether infants are attuned to changes in coordinate information, or whether infants are sensitive to coordinate changes only when they have categorical implications. Critically, the design of the current study eliminates an interpretation of the results based on the proximity of Starry to the ball. If infants had relied on Starry's distance from the ball to solve the task, then the *across-category* trial, which is always the mirror image of the habituation trial and therefore the same distance from the ball, would have been more similar to the habituation event than the *within-category* trial, in which Starry's path is more removed from the central ball. In this case, infants should have only dishabituated to the within-category coordinate change. The results do not support this interpretation. Infants' global discrimination of changes in the categorical relationship suggests that they are most sensitive to categorical changes. However, there is some evidence that efficient habituation was correlated to infants' discrimination of coordinate changes. Thus, the categorical results do not mean that infants are universally *unable* to process the coordinate change, only that categorical changes are more significant to preverbal infants than are distance changes.

These results are not surprising given that coordinate information, but not categorical information, changes during the course of dynamic events. By definition, coordinates identify a specific point in space as defined by an x- and y-coordinate. Although coordinates remain constant in static scenes, they necessarily change throughout dynamic events as people and objects move through space. In contrast, categories make coarser distinctions and can be applied to both static and dynamic events. By way of example, if the video showing Starry moving *over* the ball were paused after each frame, Starry's coordinate information would be different after each pause, but the categorical relationship between Starry and the ball would always be *over*. Thus, when infants in the current task were asked to distinguish dynamic events based on a combination of coordinate and categorical information, they understandably preferred the categorical cues, since they proved to be consistent throughout the dynamic event.

Second, the current design moves beyond investigating either coordinate information *or* categorical information to gauge infant discrimination of dynamic spatial relations in the context of multiple changing dimensions (Quinn, 1994). By manipulating both coordinate and categorical information, we presented infants with a scene that is much closer to the complex dynamic events they encounter in the world. As in the puddle-jumping example, infants were confronted with both coordinate and categorical cues. Whereas one person might jump a few centimeters over the puddle and land in the water, another person might jump higher over the puddle, but land on the other side of the puddle. Both events share the category *over*, but vary in their coordinate information. Infants must learn to recruit both kinds of cues for different purposes. Coordinate information might be particularly useful if a toddler wants to jump over the puddle himself, but categorical relationships are critical for talking about the event later as the child would likely talk about whether the person landed in the puddle or on the other side. Toddlers are unlikely to talk about the height of the jump. In fact, the height of the jump may be a distinction only privileged by track and field experts. Although the current animated stimuli do not approximate all of the complexities of the real world, manipulating both coordinate and categorical relations within an event is the first step toward examining the kinds of events infants encounter in the world.

*Implications for infant language acquisition*

That preverbal infants preferentially distinguish changes in relational categories, and not merely coordinate information, suggests that very young children carve their world in a language-ready manner. Categorical relationships in dynamic events will eventually define prepositions like *over, under*, *between*, or *behind*. This finding is consistent with prior research on motion events suggesting that infants are able to discriminate and categorize components of events like path, manner, figure and ground (Göksun et al., 2009; Göksun, Hirsh-Pasek & Golinkoff, 2010; Pruden et al., 2004; Pulverman et al., 2008).

One characteristic finding of the event components literature is that preverbal infants appear to universally discriminate and categorize at least some components of dynamic events, regardless of whether the distinction is expressed in their native language (Choi, 2006a, 2006b; Choi & Bowerman, 1991; Gentner & Bowerman, 2009; Göksun et al., 2009; Göksun et al., 2010; Hespos & Spelke, 2004). That is, at some point early in development, infants around the world may be sensitive to similar kinds of categorical relations; exposure to a language may cause some of these categorical relations to increase in importance and others to fade. For example, English describes a variety of actions as *crossing*, such as ***crossing*** *the street*, ***crossing*** *a railroad* or ***crossing*** *a field*, yet Japanese describes this same set of events with two different categorical verbs, depending on whether the ground of the event is defined by boundaries (e.g., road or railroad), or whether the ground is an open space (e.g., field). Recent evidence suggests that preverbal infants in the United States and in Japan discriminate and categorize grounds according to the Japanese distinctions, regardless of their native exposure. As children begin to learn their ambient language, they only maintain sensitivity to the contrasts encoded in their language. By 19 months of age, English-reared children are no longer sensitive to the Japanese ground distinctions whereas children living in Japan continue to distinguish bounded and open grounds (Göksun et al., 2009; Göksun et al., 2010). These findings parallel infants' early abstraction of containment-support events with regard to degree-of-fit relationship between objects as encoded in Korean, but not in English. By learning their native language, toddlers heighten or dampen categorical distinctions consistent with their native language (e.g., Choi, 2006a; Hespos & Spelke, 2004).

Cross-linguistic research is needed to determine whether infants raised in different language environments carve the same categories from continuous events. Given previous research on differences in the way that languages parse continuous space into categories (Gentner & Bowerman, 2009), future studies might investigate cross-linguistic differences in how children carve distance away from the self into categories of spatial demonstratives (Coventry, Valdés, Castillo, & Guijarro-Fuentes, 2008; Kemmerer, 1999, 2006; Longo & Lourenco, 2006). Research in this domain would provide additional robust evidence linking infants' ability to map the dual systems of coordinate and categorical information onto language.

*Implications for theories of language learning*

Theories of language learning have long suggested that words describing spatial relationships, like motion verbs and prepositions, are particularly difficult for children to learn (Childers & Tomasello, 2002, 2006; Gentner, 1982; Gentner & Boroditsky, 2001; Golinkoff, Jacquet, Hirsh-Pasek & Nandakumar, 1996; Naigles, Hoff & Vear, 2009; Tardif, Fletcher, Zhang, Liang & Zuo, 2008). Research has supported the idea that "it is not perceiving relations but packaging and lexicalizing them that is difficult" (Gentner, 1982, p. 326), indicating that children's trouble with verb learning occurs in the mapping of word to world (Gentner & Bowerman, 2009; Golinkoff et al., 2002; Golinkoff & Hirsh-Pasek, 2008).

Previous explanations of the mapping problem have centered on perceptual saliency, or the concreteness of events as a reason that labeling actions is difficult for children. Gentner (1982), for example, suggests that "verbs…have a less transparent relation to the perceptual world" (p. 328) and will therefore be learned relatively later than nouns. Others have noted that the Mapping Problem is related to the concreteness, or imageability of the referent, such that more concrete concepts do not suffer from the Mapping Problem as much as concepts that are easily imagined (Gillette, Gleitman, Gleitman & Lederer, 1999; Ma, Golinkoff, Hirsh-Pasek, McDonough & Tardif, 2009; Quine, 1960). The word *cup* arouses an image relatively easily compared to the word *pull*. That is, actions are generally less imageable than objects, so verbs will typically be learned later than nouns.

The current research may offer another explanation for the mapping problem. Whereas events unfold in the world on a dynamic continuum, language forces us to label these events categorically (Kosslyn, 2006; Martin et al., 2008; Regier & Carlson, 2001). Thus, when children attempt to label actions, they must successfully integrate two distinct coding systems: a coordinate system and a categorical system. Consider the *jumping over a puddle* example from the beginning of this paper. To learn the motion verb *jumping*, a child is required to extract categorical information from continuous, coordinate information. Finding the boundaries of the event – or when they are seeing an instance of the jumping category and when they are not - allows the child to isolate the event unit labeled by the motion verb, yet the ability to segment sequential events is only part of the mapping problem (see Baldwin, Baird, Saylor & Clark, 2001; Hespos, Saylor & Grossman, 2009). Children must also encode the coordinate and categorical properties within the segmented event, such as the distance of the jump or the fact that the jump occurred over the puddle. Ultimately, distinctions within an event unit enable the child to map an acceptable verb onto the event. Hearing a label might also facilitate the abstraction of the event components (e.g., Casasola, 2005; Pruden & Hirsh-Pasek, 2006). For example, Pruden and Hirsh-Pasek (2006) found that infants categorize a path over various manners earlier when they hear a novel verb label such as 'javing.'

Future research should investigate whether the process of mapping motion verbs onto continuous events introduces additional ambiguity into learning motion verbs. If so, it may be that learning to integrate coordinate and categorical information is critical for language-learning children who must conquer the mapping problem.

*Conclusions*

The ability to categorize events despite variability in coordinate and categorical information is a critical skill for learning motion verbs and prepositions. Our results suggest that when infants are confronted with both coordinate and categorical information in dynamic events, they privilege categorical cues. Infants' preference for distinguishing categorical changes parallels research to suggest that even preverbal children might view the world in a language-ready fashion. Cross-linguistic studies are needed to validate our findings. Finally, the current study informs a growing literature on the acquisition of spatial language by highlighting these terms as the meeting point of coordinate and categorical systems.

References

Baillargeon, R. (1987). Object permanence in 3.5- and 4.5-month-old infants. *Developmental Psychology*, *23*, 655-664.

Baillargeon, R. & Graber, M. (1987). Where's the rabbit? 5.5-month-old infants' representation of the height of a hidden object. *Cognitive Development*, *2*, 375-392.

Baldwin, D., Baird, J., Saylor, M., & Clark, M. (2001). Infants parse dynamic action. *Child Development*, *72*, 708-717.

Bornstein, M.H. (1985). Habituation of attention as a measure of visual information processing in human infants: Summary, systematization, and synthesis. In G. Gottlieb & N.A. Krasnegor (Eds.), *Measurement of audition and vision during the first year of postnatal life: A methodological overview* (pp. 253-300). Norwood, NJ: Ablex.

Bornstein, M.H. (1989). Stability in early mental development: From attention and information processing in infancy to language and cognition in childhood. In N.A. Krasnegor (Ed.), *Stability and continuity in mental development: Behavioral and biological perspectives* (pp. 147-170). Hillsdale, NJ: L. Erlbaum.

Bowerman, M. (1996). Learning how to structure space for language: A crosslinguistic perspective. In P. Bloom, M.A. Peterson, L. Nadel & M.F. Garrett (Eds.), *Language and space* (pp. 385-436). Cambridge, MA: The MIT Press.

Carlson-Radvansky, L.A. & Irwin, D.E. (1993). Frames of reference in vision and language: Where is above? *Cognition, 46,* 223-244.

Casasola, M. (2005). Can language do the driving? The effect of linguistic input on infants' categorization of support spatial relations. *Developmental Psychology, 41,* 183-192.

Casasola, M., Cohen, L.B. & Chiarello, E. (2003). Six-month-old infants' categorization of containment spatial relations. *Child Development, 74,* 679-693.

Cashon, C.H. & Cohen, L.B. (2000). Eight-month-old infants' perception of possible and impossible events. *Infancy, 1,* 429-446.

Childers, J.B., & Tomasello, M. (2002). Two-year-olds learn novel nouns, verbs, and conventional actions from massed or distributed exposures. *Developmental Psychology, 38,* 967-978.

Childers, J. & Tomasello, M. (2006). Are nouns easier to acquire than verbs? In K. Hirsh-Pasek & R. Golinkoff (Eds.), *Action meets word: How children learn verbs.* Oxford U. Press.

Choi, S. (2006a). Influence of language-specific input on spatial cognition: Categories of containment. *First Language, 26(2),* 207-232.

Choi, S. (2006b). Preverbal spatial cognition and language-specific input: Categories of containment and support. In K. Hirsh-Pasek & R.M. Golinkoff (Eds.), *Action Meets Word: How Children Learn Verbs*. New York: Oxford University Press.

Choi, S. & Bowerman, M. (1991). Learning to express motion events in English and Korean: The influence of language-specific lexicalization patterns. *Cognition, 41*, 83-121.

Cifuentes-Ferez, P. & Gentner, D. (2006). Naming motion events in Spanish and English. *Cognitive Linguistics*, *17*, 443-462.

Cohen, L.B. (2004). Uses and misuses of habituation and related preference paradigms. *Infant and Child Development, 13*, 349-352.

Cohen, L. B., Atkinson, D. J., & Chaput, H. H. (2000). *Habit 2000: A new program for testing infant perception and cognition*. (Version2.2.5c) [Computersoftware]. Austin, TX: University of Texas.

Cohen, L.B., & Oakes, L.M. (1993). How infants perceive a simple causal event. *Developmental Psychology*, *29*, 421-433.

Colombo, J., Shaddy, D.J., Richman, W.A., Maikranz, J.M., & Blaga, O.M. (2004). The developmental course of habituation in infancy and preschool outcome. *Infancy, 5*, 1-38.

Coventry, K.R., Prat-Sala, M., & Richards, L. (2001). The interplay between geometry and function in the comprehension of over, under, above and below. *Journal of Memory and Language, 44*, 376-398.

Coventry, K.R., Valdés, B., Castillo, A., & Guijarro-Fuentes, P. (2008). Language within your reach: Near-far perceptual space and spatial demonstratives. *Cognition, 108*, 889-895.

Crawford, L.E., Regier, T. & Huttenlocher, J. (2000). Linguistic and non-linguistic spatial categorisation. *Cognition, 75*, 209-235.

DeLoache, J.S. (1976). Rate of habituation and visual memory in infants. *Child Development, 47*, 145-154.

Duffy, S., Huttenlocher, J., Levine, S. & Duffy, R. (2005). How infants encode spatial extent. *Infancy, 8*, 81-90.

Frick, J.E., Colombo, J., & Saxon, T.F. (1999). Individual and developmental difference in disengagement of fixation in early infancy. *Child Development, 70,* 537-548.

Gentner, D. (1978). On relational meaning: The acquisition of verb meaning. *Child Development, 49,* 988-998.

Gentner, D. (1982). Why nouns are learned before verbs: Linguistic relativity versus natural partitioning. In S. Kuczaj (Ed.), *Language development: Language, thought, and culture, Volume 2 (*pp. 301-334). Hillsdale, NJ: Lawrence Erlbaum Associates.

Gentner, D. & Boroditsky, L. (2001). Individuation, relativity, and early word learning. In M. Bowerman & S.C. Levinson (Eds.). *Language acquisition and conceptual development* (pp. 215-256). New York, NY: Cambridge University Press.

Gentner, D. & Bowerman, M. (2009). Why some spatial semantic categories are harder to learn than others: The typological prevalence hypothesis. In J. Guo, E. Lieveb, S. Ervin-Tripp, N. Budwig, S. Özcaliskan, & K. Nakamura (Eds.). *Crosslinguistic approaches to the psychology of language: Research in the tradition of Dan Isaac Slobin*. NJ, New York: Lawrence Erlbaum Associates.

Gillette, J., Gleitman, H., Gleitman, L., & Lederer, A. (1999). Human simulations of vocabulary learning. *Cognition, 73,* 135-176.

Göksun, T., Hirsh-Pasek, K. & Golinkoff, R.M. (2009). Processing figures and grounds in dynamic and static events. In J. Chandlee, M. Franchini, S. Lord & G. Rheiner (Eds.), *Proceedings of the 33rd Annual Boston University Conference on Language Development, Volume 1* (pp. 199-210). Somerville, MA: Cascadilla Press.

Göksun, T., Hirsh-Pasek, K. & Golinkoff, R.M. (2010). Trading spaces: Carving up events for language learning. *Perspectives on Psychological Science, 5,* 33-42.

Golinkoff, R.M., Chung, H.L., Hirsh-Pasek, K., Liu, J., Bertenthal, B.I., Brand, R., Maguire, M.,

& Hennon, E. (2002). Young children can extend motion verb labels to point-light displays. *Developmental Psychology, 38,* 604-614.

Golinkoff, R.M. & Hirsh-Pasek, K. (2008). How toddlers begin to learn verbs. *Trends in Cognitive Science*, *12*, 397-403.

Golinkoff, R.M., Jacquet, R., Hirsh-Pasek, K., & Nandakumar, R. (1996). Lexical principles may underlie the learning of verbs. *Child Development*, *67*, 3101-3119.

Halstead, D. & Forbus, K. (2007). Some effects of a reduced relational vocabulary on the Whodunit problem. Proceedings of the IJCAI-2007, Hyderabad, India.

Hayward, W.G. & Tarr, M.J. (1995). Spatial language and spatial representation. *Cognition, 55*, 39-84.

Hespos, S.J. & Baillargeon, R. (2001). Knowledge about containment events in very young infants. *Cognition, 78*, 204-245.

Hespos, S., Saylor, M., & Grossman, S. (2009). Infants' ability to parse continuous actions. *Developmental Psychology*, *45*, 575-585.

Hespos, S.J. & Spelke, E.S. (2004). Conceptual precursors to language. *Nature, 430,* 453-456.

Huttenlocher, J., Duffy, S., & Levine, S. (2002). Infants and toddlers discriminate space: Are they measuring? *Psychological Science, 13*, 244-249.

Huttenlocher, J., Hedges, L.V. & Duncan, S. (1991). Categories and particulars: Prototype effects in estimating spatial location. *Psychological Review, 98*, 352-376.

Jackendoff, R. (1983). *Semantics and cognition: Current studies in linguistics series, No. 8.* Cambridge, MA: The MIT Press.

Johnson, S.P., Bremner, J.G., Slater, A.M., & Mason, U.C. (2000). The role of good form in young infants' perception of partially occluded objects. *Journal of Experimental Child Psychology, 76*, 1-25.

Kemmerer, D. (1999). "Near" and "far" in language and perception. *Cognition, 73*, 35-63.

Kemmerer, D. (2006). The semantics of space: Integrating linguistic typology and cognitive neuroscience. *Neuropsychologia, 44*, 1607-1621.

Kosslyn, S.M. (1987). Seeing and imagining in the cerebral hemispheres: A computational approach. *Psychological Review, 94*, 148-175.

Kosslyn, S.M. (2006). You can play 20 questions with nature and win: Categorical versus coordinate spatial relations as a case study. *Neuropsychologia*, *44*, 1519-1523.

Kosslyn, S.M., Thompson, W.L., Gitelman, D.R., & Alpert, N.M. (1998). Neural systems that encode categorical vs. coordinate spatial relations: PET investigations. *Psychobiology, 26*, 333–347.

Laeng, B. (1994). Lateralization of categorical and coordinate spatial functions: A study of unilateral stroke patients. *Journal of Cognitive Neuroscience, 6*, 189–203.

Laeng, B., Chabris, C.F., & Kosslyn, S.M. (2003). Asymmetries in encoding spatial relations. In R. Davidson & K. Hugdahl (Eds.), *The asymmetrical brain*. Cambridge: The MIT Press.

Lakusta, L., Wagner, L., O'Hern, K. & Landau, B. (2007). Conceptual foundations of spatial language: Evidence for a goal bias in infants. *Language Learning and Development, 3*, 179-197.

Landau, B. & Jackendoff, R. (1993). What and where in spatial language and spatial cognition. *Behavioral and Brain Sciences, 16*, 217-265.

Longo, M.R. & Lourenco, S.F. (2006). On the nature of near space: Effects of tool use and the transition to far space. *Neuropsychologia, 44*, 977-981.

Ma, W., Golinkoff, R. M., Hirsh-Pasek, K., McDonough, C., & Tardif, T. (2009). Imageability predicts verb learning in Chinese children. *Journal of Child Language*. *36*. 405-423.

Martin, R., Houssemand, C., Schiltz, C., Burnod, Y. & Alexandre, F. (2008). Is there continuity between categorical and coordinate spatial relations coding? Evidence from a grid/no-grid working memory paradigm. *Neuropsychologia, 46*, 576-594.

Miller, D.J., Ryan, E.B., Short, E.J., Ries, P.G., McGuire, M.D., & Culler, M.P. (1977). Relationships between early habituation and later cognitive performance in infancy. *Child Development, 48*, 658-661.

Mix, K.S., Huttenlocher, J., & Levine, S.C. (2002). Multiple cues for quantification in infancy: Is number one of them? *Psychological Bulletin, 128*, 278-294.

Naigles, L., Hoff, E., & Vear, D. (2009). Flexibility in early verb use: Evidence from a multiple-n diary study. *Monographs of the Society for Research in Child Development, 74 (2).*

Newcombe, N.S. & Huttenlocher, J. (2006). Development of spatial cognition. In D. Kuhn & R.S. Siegler (Eds.), *Handbook of child psychology* (6th edition, pp. 734-776). John Wiley and Sons.

Newcombe, N., Huttenlocher, J., & Learmonth, A. (1999). Infants' coding of location in continuous space. *Infant Behavior & Development*, *22*, 483-510.

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

Pruden, S.M., & Hirsh-Pasek, K. (2006). Foundations of verb learning: Labels promote action category formation. In D. Bamman, T. Magnitskaia & C. Zaller (Eds.), *Proceedings of the 30th Annual Boston University Conference on Language Development* (pp.476-488). Somerville, MA: Cascadilla Press.

Pulverman, R., Golinkoff, R.M., Hirsh-Pasek, K. & Buresh, J.S. (2008). Infants discriminate manners and paths in non-linguistic dynamic events. *Cognition, 108,* 825-830.

Quine, W. V. O. (1960). *Word and object*. Cambridge, England: Cambridge University Press.

Quinn, P.C. (1994). The categorization of above and below spatial relations by young infants. *Child Development, 65*, 58-69.

Quinn, P.C. (2007). On the infant's prelinguistic conception of spatial relations: Three developmental trends and their implications for spatial language learning. In J.M. Plumert & J.P. Spencer (Eds.), *The emerging spatial mind*. New York, NY, Oxford University Press.

Quinn, P.C., Cummins, M., Kase, J., Martin, E., & Weissman, S. (1996). Development of categorical representations for above and below spatial relations in 3- to 7-month-old infants. *Developmental Psychology, 32,* 642-650.

Quinn, P.C., Polly, J.L., Furer, M.J., Dobson, V., & Narter, D.B. (2002). Young infants' performance in the object-variation version of the above-below categorization task: A result of perceptual distraction or conceptual limitation? *Infancy, 3,* 323-347.

Regier, T. & Carlson, L. (2001). Grounding spatial language in perception: An empirical and computational investigation. *Journal of Experimental Psychology: General, 130,* 273-298.

Roseberry, S., Göksun, T., Hirsh-Pasek, K., Newcombe, N., Golinkoff, R., Novack, M., &

Brayfield, R. (2009, April). Individual differences in early event perception predict later verb learning. Poster presented at the Society for Research in Child Development, Denver, CO.

Samuelson, L.K., & Smith, L.B. (1998). Memory and attention make smart word learning: An alternative account of Akhtar, Carpenter, and Tomasello. *Child Development, 69*, 94-104.

Schlottmann, A., Surian, L., & Ray, E. D. (2009). Causal perception of action-and-reaction sequences in 8- to 10-month-olds. *Journal of Experimental Child Psychology, 103*, 87-107.

Schöner, G., & Thelen, E. (2006). Using dynamic field theory to rethink infant habituation. *Psychological Review, 113*, 273-299.

Slaughter, V., & Suddendorf, T. (2007). Participant loss due to "fussiness" in infant visual paradigms: A review of the last 20 years. *Infant Behavior & Development, 30*, 505-514.

Talmy, L. (1985). Lexicalization patterns: Semantic structure in lexical forms. In T. Shopen (Ed.), *Language typology and syntactic description* (pp. 57-149). New York, NY: Cambridge University Press.

Talmy, L. (2000). *Toward a cognitive semantics, Vol. II: Typology and process in concept structuring.* Cambridge, MA: The MIT Press.

Tamis-LeMonda, C.S., & Bornstein, M.H. (1989). Habituation and maternal encouragement of attention in infancy as predictors of toddler language, play, and representational competence. *Child Development, 60*, 738-751.

Tardif, T., Fletcher, P., Zhang, Z. X., Liang, W. L. & Zuo, Q. H. (2008). *The Chinese Communicative Development Inventory (Putonghua and Cantonese versions): Manual, forms, and norms*. Beijing: Peking University Medical Press.

U.S. Census Bureau (2000). *Fact Sheet by Zip Code*. Retrieved May 25, 2010, from http://factfinder.census.gov.

Wang, S. & Baillargeon, R. (2006). Infants' physical knowledge affects their change development. *Developmental Science, 9*, 173-181.

Wolfe, C.D., & Bell, M.A. (2004). Working memory and inhibitory control in early childhood: Contributions from physiology, temperament, and language. *Developmental Psychobiology, 44*, 68-83.

Figure 1.

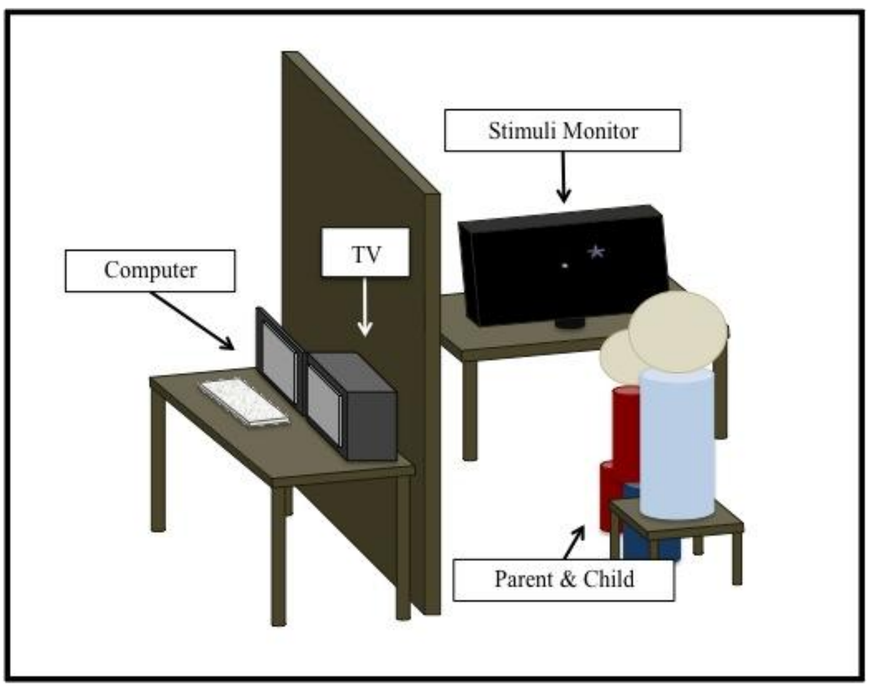


Figure 2.

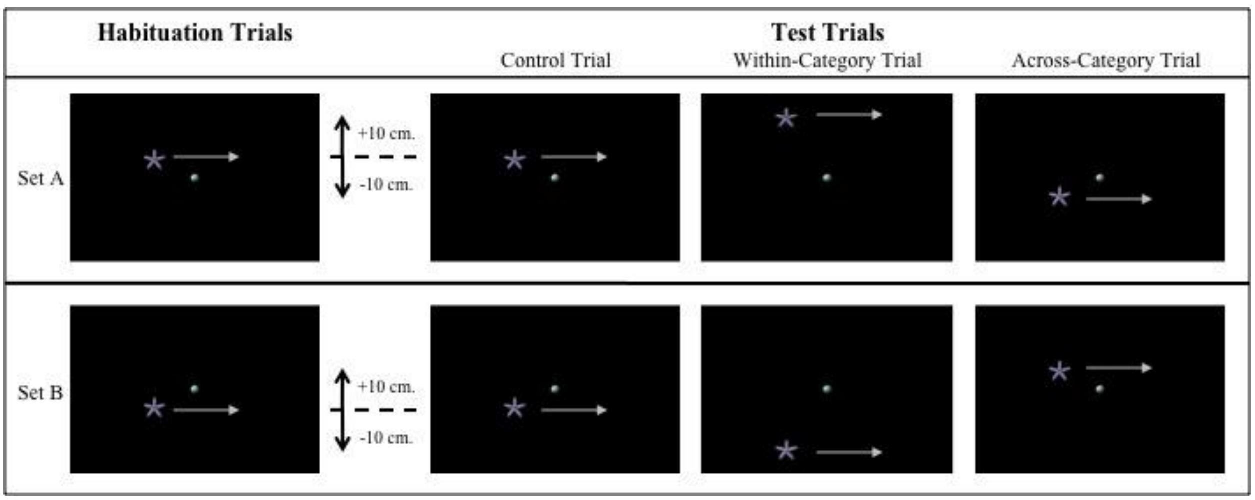
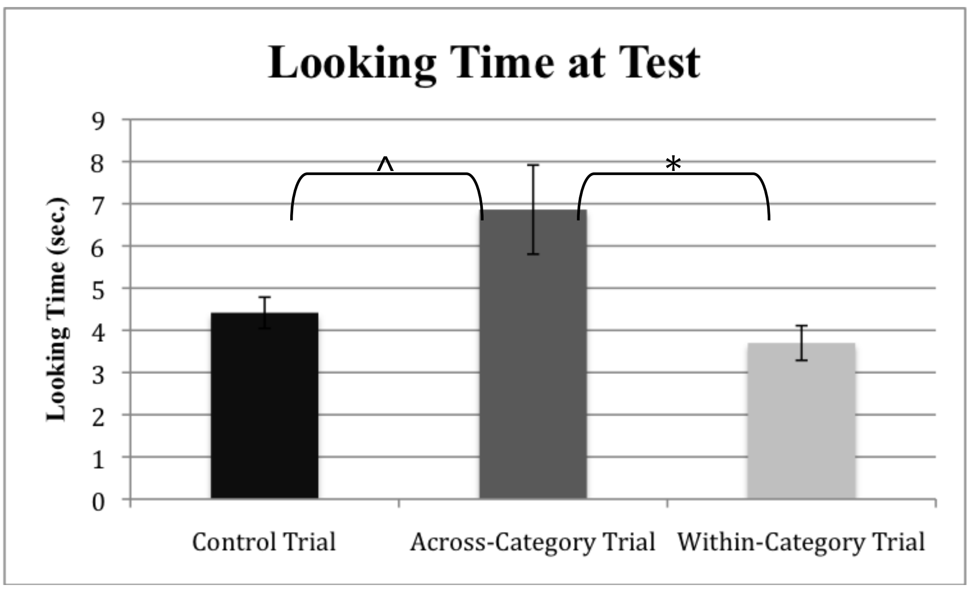

Habituation Trials
Test Trials
Control Trial
Within-Category Trial
Across-Category Trial
Set A
+10 cm.
-10 cm.
Set B
+10 cm.
-10 cm.

Figure 3.


Looking Time at Test
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9
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Control Trial
Across-Category Trial
Within-Category Trial

Figure Captions

Figure 1. Set-up of the habituation paradigm.

Figure 2. Design of the current study. Infants saw either Set A or Set B of the stimuli. Infants were habituated to Starry traveling either *over* (+5 centimeters) or *under* (-5 centimeters) the central ball. Three counterbalanced test trials presented a *control trial* and two change test trials that showed a uniform distance change in opposing directions (+10 centimeters, -10 centimeters). Both change test trials were novel to infants. In the *within-category trial*, Starry moved at a new location, but in the same category relative to the ball as seen during habituation. In the *across-category trial*, Starry traveled in a new location that was also in a new category relative to the ball.

Figure 3. Infant looking time to each of the three test trials: control, within-category, across-category. Significance criteria accounts for Bonferroni adjustments for multiple comparisons (.0167). * $p < .01$, ^ $p = .02$