Infant categorization of containment, support and tight-fit spatial relationships

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In press: Developmental Science

Abstract

Two experiments examined infant categorization of containment, support, or tight-fit spatial relationships. English-learning infants of 10 months (Experiment 1) and 18 months (Experiment 2) were habituated to four pairs of objects in one of these relationships. They were then tested with one event from habituation, one with novel objects in the familiar relationship, one with familiar objects in a novel relationship, and one with novel objects in a novel relationship. Infants at both ages generalized their habituation of the containment relationship to novel objects in this relationship. In the support and tight-fit conditions, the younger infants responded only to the novel objects in the test while the older infants responded to the novel relationship, but only with familiar objects. The results indicate that infants learn to categorize containment prior to support or tight-fit relationships and suggest that infants can recognize a relationship between familiar objects prior to novel objects.

Keywords: Infant categorization, infant spatial abilities

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In recent years, a large number of experimental studies have explored how infants recognize and categorize the objects in their environment (e.g., Bomba & Siqueland, 1983; Eimas & Quinn, 1994; Kellman, 1996; Quinn, 1998; Spelke, Breinlinger, Macomber, Jacobson, 1992; Treisman, 1986; Younger & Cohen, 1985; Younger, 1990). As our knowledge in this area continues to grow, our understanding of how infants recognize and categorize the spatial relations between objects has remained comparatively limited. Yet, infants' ability to recognize the spatial arrangement between and among objects is an important aspect of their perceptual and cognitive development. Furthermore, the ability to form abstract spatial categories is critical because it enables infants to recognize a particular spatial relationship as familiar despite changes in the objects that form the relationship. Consequently, infants can view commonalities in the relationships between objects rather than view their world as containing an endless number of spatial arrangements (Quinn, 1999), each defined by the objects making up those arrangements.

Infants' ability to attend to and recognize spatial relationships, and form spatial categories, are also necessary cognitive components in the acquisition of spatial language. To map a spatial term, such as "in," "on," or "under," onto a locative event, children must be able to recognize the spatial arrangement between two specific objects. Similarly, to generalize a spatial term to new instances of that spatial relationship, children must have an abstract representation of the relationship, independent of the objects that comprise the relationship. In early studies examining young children's acquisition of locative terms, these cognitive abilities were believed to provide young children with a universal set of spatial concepts onto which spatial language was later mapped (Slobin, 1973). Hence, the order in which young English-speaking children could comprehend and produce the corresponding spatial terms was taken as an indication of the order in which they could discern particular spatial relationships (Johnston, 1981, 1985; Washington & Naremore, 1978). Researchers who conducted cross-linguistic studies of children's early spatial words drew a similar conclusion. These language researchers surmised that both the cognitive complexity of the underlying spatial concept and the complexity of the linguistic forms children had to master in order to express these spatial concepts dictated which spatial words across languages young children first produced (Johnston, 1988; Johnston & Slobin, 1979).

More recently, however, language researchers have wondered about the nature of young children's nonlinguistic spatial concepts. In particular, researchers have expressed interest in delineating the spatial relationships that infants can recognize and group into a spatial category prior to the time that they begin to acquire spatial language (Bowerman, 1989). This interest has been motivated by several cross-linguistic findings documenting language-specific effects on young children's descriptions of spatial events (Sinha, Thorseng, Hayashi, & Plunkett 1994). In one study of early semantic development, Choi and Bowerman (1991) found that the English and Korean-speaking children differed markedly in how they grouped spatial relationships into categories and matched these spatial categories with a particular spatial morpheme. That is, the children appeared to organize spatial events into language-specific semantic categories (i.e., the category of spatial events that corresponds to a particular linguistic term such as "in"). For example, Choi and Bowerman found that the English-speaking children labeled containment events with “in” and support events with “on.” In contrast, Korean children organized these same events on the basis of the fit between two objects and labeled those that were interlocking as “kkita,” a Korean semantic category used to describe either containment or support events with a tight fit between the objects. Choi, McDonough, Bowerman and Mandler (1999) found the same to be true of 18- to 23-month-old English- and Korean-speaking children’s comprehension of “in” and “kkita,” respectively. That is, when shown identical pairs of scenes depicting a spatial arrangement between objects, English children looked longer at the containment event in the pair of scenes when hearing “in” while the Korean children looked longer at the tight-fit events when hearing “kkita.” Thus, for the purposes of linguistic expression, children group spatial relationships into semantic spatial categories that are language-specific, focusing on those relationships that are relevant for the spatial terms of their language rather than grouping spatial relationships on a cognitively universal basis.

In speculating about how children acquire language-specific semantic categories, one issue has been the extent to which young children rely on their existing nonlinguistic spatial categories to form language-specific semantic categories (Bowerman, 1989). As one possibility, Mandler (1996) has suggested that young children enter the word-learning task with a set of meanings, or image-schemas (see Mandler, 1992), that are consistent with the spatial words first acquired by children. Thus, similar to the traditional views posited by Slobin (1973), Mandler argues that young children map a particular spatial term onto their existing nonlinguistic notions about space, only that children’s nonlinguistic meanings are more refined than previously believed. In particular, Mandler has proposed that tight-fit, along with containment and support, are among the early spatial meanings accessible to prelinguistic infants, regardless of whether their language encodes these spatial relationships as a spatial term. She argues that all preverbal infants form these meanings independently of language as a result of the manner in which infants attend to and analyze their spatial world. Thus, according to Mandler, children's earliest spatial morphemes are mapped onto existing meanings formed independently of language. In addition, she posits that cross-linguistic differences in semantic spatial categories result directly from the manner in which nonlinguistic spatial meanings structure languages. Alternatively, Bowerman and others have suggested that input from language may play an important role in young children's ability to group spatial events into particular semantic categories (Bowerman, 1989, 1996a, 1996b; Choi & Bowerman, 1991; Gentner, 1982; Gentner & Boroditsky, in press; Schlesinger, 1977). Their views are similar to those advanced by Gopnik and her colleagues in which language is posited to drive the acquisition of particular concepts (Gopnik & Choi, 1990; Gopnik Choi, & Baumberger, 1996; Gopnik & Meltzoff, 1984). Likewise, Bowerman and her colleagues have posited that young children may not necessarily form spatial categories consistent with all semantic categories until they are motivated by their language to do so.

An important first step in understanding how young children form language-specific semantic spatial categories is to examine the types of spatial categories infants form, prior to and during the time that they begin to acquire spatial language. Although relatively few, a handful of studies have examined which spatial relationships infants discriminate (i.e., recognize the relationship as distinct from other types of relationships) and can group into a spatial category (i.e., recognize the relationship independent of specific objects). In one study, Antell and Caron (1985) found that newborn infants could discriminate the above versus below spatial arrangement of two simple forms, such as a cross and a square. Hence, even at a very young age, infants demonstrate the ability to recognize the spatial relationship between two objects. Other research, using the familiarization-novelty preference procedure, has found that preverbal infants can form a category of particular spatial relationships by about 3 months of age. Behl-Chadha and Eimas (1995) reported that 3- and 4-month-old infants abstract the left-right relationship between a horse paired with a zebra, despite viewing different pairs of these animals, in different sizes and in different locations on a stimulus card. Similarly, Quinn (1994) reported that 3-month-old infants form a category of “above” and “below” spatial relationships. In his study, infants were familiarized to different instances of a dot either above or below a reference object, a solid bar. During the test, infants responded to a dot in a new location on the familiar side of the bar as familiar but responded to an event with the dot on the opposite side of the bar as novel. Quinn, Norris, Pasko, Schmader, and Mash (1999) also showed that 6-month-old infants form a category of the spatial relationship “between.” After being familiarized to a diamond in different locations between two bars, infants looked significantly longer at the test trial with a diamond on the outside of the bars than at the test trial with a diamond in a new location between the bars. Thus, within the first six months, infants have the ability to categorize different examples of the same spatial relationship.

The research findings reported by Quinn and his colleagues have been particularly important in demonstrating developmental changes in infants’ ability to form a category of spatial relationships. First, Quinn has found differences in the types of spatial categories that infants form. Although infants of 3 months of age form a category of above versus below, they are unable to form a category of the relationship between. In contrast, infants of 6 months successfully form this category (Quinn et al., 1999). Second, Quinn has reported developmental changes in how infants form spatial categories. If they view a single dot presented in different locations either above or below a bar during the familiarization phase, 3-month-old infants easily form a category of above versus below. That is, infants look significantly longer at the dot on the opposite side of the bar than at the dot in a new location on the familiar side of the bar (Quinn, 1994). In addition, if they are familiarized to different forms, such as an arrow, a dot, and a diamond, and then view one of these forms during the test phase, 3-month-old infants also form the category (Quinn et al., 1998). However, when familiarized to different forms and then tested with novel forms, one in the familiar relationship and one in a novel relationship, 3-month-old infants no longer form a category of above versus below whereas 6 month-old infants do (Quinn et al., 1996). Thus, the 6-month-old infants appear to recognize the above and below relationship independent of the objects while the younger infants appear to recognize the relationship only if they are first familiarized with the forms that comprise the relationship.

Quinn found the same pattern of results with infants' ability to form a category of between. When infants of 6 months were familiarized to a diamond in different locations between two reference bars (Quinn et al., 1999), they looked significantly longer at the diamond that appeared outside of the bars rather than the diamond that appeared in a new location between the two bars. Hence, infants responded in a manner consistent with having formed a category of between. Infants demonstrated this same pattern of looking when they were familiarized to different forms between the bars and were tested with one of these forms (Quinn, 2000). In contrast, when familiarized to a number of different forms and then tested with novel forms, 6-month-olds did not form a category of between whereas infants of 9- to 10-months were able to do so (Quinn, 2000). Based on these results, Quinn (in press) has argued that infants first learn to recognize the spatial relationship between a specific pair of objects and only at a later point in development learn to abstract the relationship from the objects depicting them to form a spatial category.

Thus, the findings reported by Quinn and his colleagues have been pivotal in advancing our understanding of the types of spatial categories that infants can form and the developmental progression by which they do so. Nevertheless, many aspects of infant spatial categorization remain unexplored. One unresolved issue, raised by Quinn (in press) himself, is whether infants can form a spatial category when more realistic objects are used in the events. Thus far, many of the experimental studies have used very simple stimuli consisting of forms such as a black dot, a diamond, an arrow, or a dollar sign. It is unknown whether the infants would still form a spatial category when faced with more ecologically valid objects, such as toys, rather than forms. Furthermore, in all the studies reported above, infants were tested on their ability to recognize a particular spatial relationship when the same referent object (e.g., a solid bar or a pair of lines) was used throughout the experiment. Yet, in their daily encounters with objects in a particular relationship, infants view the objects in relation to changing referents. From the existing research findings, it remains uncertain whether infants can still form a spatial category when both the referent object and the objects in relationship to that referent vary. Finally, none of the studies have attempted to link infants' nonlinguistic spatial categories with the different semantic spatial categories young children later seem to use when acquiring spatial language.

The following experiments were designed to address these issues. First, the studies examine whether infants form a spatial category when more complex objects are used. Rather than simple forms, the studies present toys in various spatial relationships to one another. Second, the studies explore infants' ability to form spatial categories when the referent object in the event also varies across the familiarization trials. Consequently, the current studies present a more challenging task to infants than the category tasks used in previous research.

In addition, the studies begin to explore the relationship between infants' nonlinguistic spatial categories and the semantic spatial categories that young children form when acquiring spatial language. Because Choi et al. (1999) found that 18- to 23-month-old English- and Korean-speaking toddlers possess the semantic spatial categories of "in" and "kkita," respectively, it seemed appropriate to examine infants' ability to form spatial categories of containment and tight-fit relationships. Examining infants' ability to attend to and form a spatial category of tight-fit seemed particularly interesting given that Mandler (1996) has argued that tight-fit is among the early spatial relationships to which infants are sensitive. Infants' ability to form a category of support relationships also was examined, in large part because "on," along with "in," is among the early locative spatial terms acquired by English-speaking children (Brown, 1973; Johnston & Slobin, 1979; Tomasello, 1987). In addition, the notion of support, along with the notions of containment and tight-fit, has been argued by Mandler (1992, 1996) to be among the early spatial meanings acquired by preverbal infants.

It should be acknowledged that several experimental studies have examined infants' and young children's ability to process containment and support events (e.g., Aguiar & Baillargeon, 1998; Baillargeon & Hanko-Summers, 1990; Baillargeon, Needham, & DeVos, 1992; Caron, Caron, & Antell, 1988; Keil, 1979; MacLean & Schuler, 1989; Needham & Baillargeon, 1993; Sitskoorn & Smitsman, 1995). While documenting that infants and young children show surprise when viewing a physically impossible event, these studies did not examine infants' ability to recognize these relationships across a number of different objects. In other words they did not test whether infants perceive or understand that a particular spatial relationship (e.g., containment) is the same even when different objects are used.

Although only English-learning infants were tested in the current studies, the inclusion of the tight-fit condition provided the opportunity to explore whether infants, with no exposure to Korean, form a spatial category consistent with a semantic spatial category not used in English. The Korean term "kkita" is used to refer to those dynamic events in which an object is fitted tightly or interlocks with another object and is applied to both containment and support events (Choi & Bowerman, 1991). Thus, a peg that is seen being fitted exactly in a hole and a Lego block that is viewed being placed tightly on another Lego block are both described as "kkita" in Korean even though these events fall into two different semantic categories in English (i.e., "in" and "on," respectively[1]). That is, while the English categories of containment and support are mutually exclusive, the category of tight-fit is not mutually exclusive of containment and support and in fact, overlaps the containment and support English semantic categories. Hence, one question the current studies explores is whether infants can disregard the containment or support relationship between two objects and instead attend to the tight-fit relationship in forming a spatial category.

To understand which spatial categories infants can form prior to acquiring spatial language and which they form after the onset of spatial language acquisition, both a younger and older age-group of infants are tested in the current experiments. Experimental and diary studies have shown the comprehension and production of locative spatial terms, such as “in” and “on,” to begin at about 15 to 17 months of age (e.g., Choi & Bowerman, 1991; McCune-Nicolich, 1981; Tomasello, 1987; Wilcox & Palermo, 1975). Based on these findings, 9- to 11-month-old infants are unlikely to have acquired the spatial terms for the events presented and are tested in Experiment 1. Using the same logic, 17- to 19-month-old infants were selected as the older age group and are tested with the same task in Experiment 2. Although a significant difference in spatial knowledge between the two age groups is expected, a comparison of the results from the two experiments will also indicate whether any age-related differences in the results might be influenced by the acquisition of spatial language. Thus, the results of Experiment 1, in which 9- to 11-month-old infants are tested, were expected to reveal which spatial categories younger infants form prior to their acquisition of any spatial language. The results of Experiment 2, in which 17- to 19-month-old infants are tested,

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[1] We thank Melissa Bowerman for pointing out an additional distinction between the Korean term “kkita” and the English terms “in” and “on.” Whereas “in” and “on” can be used to refer to both static and dynamic events, “kkita” is used to refer only to dynamic events.

were expected to indicate whether the spatial categories that older infants form are influenced by their experience with the semantic categories of English.

Experiment 1

In Experiment 1, 9- to 11-month-old infants' ability to form a categorical representation of a particular spatial relationship was tested. A standard infant categorization task was employed. Infants were presented with videotaped action events depicting four different pairs of objects in a particular spatial relationship (e.g., either containment, support, or tight-fit). Once infants were habituated to the four examples of the spatial relationship, they were all tested with four events: (a) one of the events seen during habituation, (b) one with familiar objects in a novel spatial relationship, (c) one with novel objects in the familiar spatial relationship, and (d) one with novel objects in a novel relationship.

Infants were expected to respond to the novel objects in the test events, but the question of interest is whether infants also respond to the novel relationship in the test events. If infants are able to categorize the events according to the spatial relationship viewed during habituation, they should respond to the novel objects in the habituation spatial relationship as more familiar than the novel objects in an unfamiliar spatial relationship. Likewise, infants should respond to the familiar objects in the habituation relationship as more familiar than familiar objects in the novel relationship. Infants' ability to respond to the habituation spatial relationship as familiar relative to an unfamiliar relationship, regardless of object familiarity or novelty, will indicate that they have formed a category of the relationship. However, if infants are not sensitive to the spatial relationship in the habituation events, then they should respond only to the changes in the object in the test trials. In sum, the current study explored infants' ability to recognize when the same spatial relationship is depicted across different pairs of objects. Because three different spatial relationships were used (containment, support, or tight-fit that includes both tight-fit containment and tight-fit support), the present study also examined which perceptual aspects of spatial events infants can recognize and use as the basis of a spatial category.

Method

Participants. Thirty-six, full-term 9- to 11-month-old infants, 18 females and 18 males, participated in the current study. Infants ranged in age from 8.5 to 11.5 months (M = 45.45 weeks, SD = 3.49 weeks, range = 37.29 – 49.71 weeks). Infants whose parents reported that they comprehended or comprehended and produced "in" and "on" were excluded from the final sample (N = 3). A number of other infants participated in the study, but their data were excluded for the following reasons: 3 heard languages other than English, 13 became either fussy or inattentive during the testing session, and 16 did not meet the habituation criterion (described below).

Names of infants were obtained from birth announcements published in the local newspaper. Parents were sent a letter describing the experiment, then contacted by telephone and invited to participate. All infants received a souvenir infant T-shirt or "sippie" cup in appreciation.

Stimuli. The stimuli were pairs of brightly colored toys or common household objects. For example, one pair of objects was a small colorful cup and a white dog bowl decorated with colorful paw prints. A second pair of objects consisted of two toy cars, one large and bright red and the second, smaller and bright blue. Three brightly colored turtles and a clear plastic pole with a red corkscrew inside were used as a third set of objects. A hole through the center of each turtle's shell allowed for the turtles to be stacked on the pole and tightly on top of one another.

A fourth pair of toys was comprised of a bright green peg that fitted tightly into a hole of a yellow rectangular block. As a fifth pair of objects, a blue and yellow stuffed monkey and a white basket were used. The sixth pair was a bright blue Lego car on bright yellow wheels and a yellow-and-red-striped cylindrical man. The Lego car contained a hump upon which the cylindrical man, who was hollow, could be locked onto tightly when placed on the Lego car. The seventh pair was rectangular Lego blocks, one green and the other red. The final pair of objects used consisted of a red candle in the shape of a ginger man and a silver cookie cutter of the same shape.

Eleven, videotaped, dynamic events were created with the pairs of objects. In each event, the object to be manipulated was located to the left of the second, larger referent object. A hand entered from the left, picked up the smaller of the two objects and placed it in a particular spatial relationship to the second object. The hand then retreated and the two objects were depicted alone and in their spatial relationship for an additional second.

The containment events were depicted by:

a. the cup in the dog bowl
b. the blue car in the inverted and hollow red car
c. the green peg in the yellow block*
d. the stuffed monkey in the basket
e. the ginger man candle in the cookie cutter*

*These events also depicted a tight-fit between the objects.

The support events were depicted by:

a. the cup on the inverted dog bowl
b. the blue car on the upright, red car
c. the turtle stacked on the pole and on the other two turtles*
d. the green peg on the yellow block
e. the cylindrical Lego man on the Lego car*

The tight-fit events were depicted by:

a. the green peg in the yellow block*
b. the ginger man candle in the cookie cutter*
c. the turtle stacked on the pole and on the other two turtles*
d. the cylindrical Lego man on the Lego car*
e. the green Lego block on the red Lego block.*

Several pairs of objects were used to depict both a containment and a support event (e.g., the cups, the cars, and the green peg and yellow block). The only difference between the containment and the support version of the events with the cups and cars is that in one event, the larger object (i.e., the dog bowl and the red car) was inverted and in the other, the object was upright. In addition, a number of tight-fit events were used as either containment or support events as well. An additional tight-fit support event was created, but was used only as a tight-fit event in the study (i.e., the green Lego block on the red Lego block). A number of adult, native Korean speakers (N = 8) confirmed that each event would be described as “kkita” in Korean. These speakers explained that because the candle was made to fit in the cookie cutter, the green peg was snug in the hole of the yellow block, the round Lego man locked onto the blue Lego car, the green Lego block snapped onto the red block, and the turtle fitted tightly on the other turtles, each of these events were instances of “kkita”.

Each event was videotaped using a Sony Hi-8 digital video camera. The events were then transferred into a Macintosh G4 computer and converted to Quicktime movies. Each event had a duration of approximately 6 s. For a trial, a particular event was repeated five consecutive times with no intervals between events to yield trials with a total duration of approximately 30 s.

Apparatus. The experiment was conducted in adjoining control and experimental rooms. Infants were seated on their parent’s lap in front of a 20-in Apple Color Synch Display monitor that was placed on a table approximately 77 cm from the floor. Infants and their parent sat approximately 125 cm from the monitor. A black wooden frame, which extended from the floor of the room to the ceiling and encased the monitor, minimized any distracting stimuli in the room. Low lighting was used to focus infants’ attention on the monitor. In addition, the experimental room contained soundproofing to reduce the possibility that any exterior noise might distract the infant during the testing session.

A small 6.5 cm hole in the wooden frame below the monitor permitted a Panasonic camera to focus on the infant. The camera was linked to a 14-inch Panasonic CT-1301M color-video monitor in the control room that allowed the experimenter to monitor infants' looking time to the events. A JVC VCR was also linked to this monitor so that each infant could be recorded and inter-observer reliability could be determined.

Each spatial event was played directly from the Macintosh G4 in the control room onto the monitor in the experimental room. A specially designed habituation program made it possible to designate the order in which events were to be presented during the habituation and test phase. This program also allowed the experimenter to begin a trial by pressing one key on the computer keyboard and record infants' visual fixations during each trial by pressing another key on the keyboard.

Design. The design of the experiment is presented in Table 1. Infants were randomly assigned to one of three conditions: containment, support, or tight-fit. In each condition, infants were habituated to four events, each of which depicted the same spatial relationship between a different pair of objects. These events appear in italics in the top portion of Table 1. Following habituation, infants viewed four test trials presented in normal type in the bottom half of Table 1. The first test trial, the familiar objects-familiar relationship trial, presented one of the events viewed during habituation. This event was the same event for all infants within a condition. A second test trial presented a novel pair of objects in the familiar spatial relationship. A third test trial presented a familiar pair of objects seen during habituation, but the objects were presented in a different spatial relationship than that seen during habituation. Finally, a fourth test trial presented a novel pair of objects in a novel spatial relationship. As with the familiar objects-familiar relationship test trial, infants within a condition viewed the same event for each of the different test trials (see the bottom half of Table 1). For infants in each condition, the familiar objects-familiar test trial (i.e., the familiar test trial) was presented as the first test trial. The order of presentation of the other three test trials was counterbalanced across participants.

Insert Table 1 about here

Across the three conditions, infants viewed the same four events during the test. The assignment of the same events to different test trials across conditions was implemented as a precaution against a priori preferences for a particular pair of objects. Thus, the design made it possible to ascertain whether infants responded to a particular event because they viewed the event as differing from the events seen during habituation or simply because of a preference for a particular pair of objects.

For infants in the containment and support conditions, half of the spatial events also depicted a tight-fit between the objects and half a loose-fit. Those events with a tight-fit are denoted in bold in Table 1. Similarly, infants in the tight-fit condition viewed half containment events and half support events throughout the experiment. Thus, within each condition, the events could be organized on the basis of containment versus support, according to the semantic pattern of English, or could be organized on the basis of tight-fit versus loose-fit, according to the semantic pattern of Korean.[2]

Procedure. Prior to the start of the experiment, parents were asked to complete a section of the MacArthur Communicative Development Inventory: Infants (Fenson et al., 1993) that asked about their child's comprehension and production of spatial prepositions. The data collected from the inventory were not analyzed. Rather, the

[2] In the current study, infants are tested on their ability to form three of these four categories (containment, support, and tight-fit), but are not tested on their ability to form a category of loose-fit events. Because Korean or any other known language, does not have a loose-fit semantic category, there was no theoretical motivation to test infants' ability to form this spatial category.

information obtained from the questionnaire was used only to exclude those infants (N = 3) who, according to their parents, understood the spatial terms “in” and “on.”

During the experiment, infants sat on their parent's lap. Parents were instructed not to watch or respond to the events. The experimenter began the session from the control room by presenting an attention-getter, a chiming and flashing green circle on the monitor in the experimental room. Once the infant attended to the monitor, the experimenter depressed a key on the computer keyboard to begin a trial. The experimenter depressed another key on the computer keyboard for as long as the infant attended to the event and its five repetitions. Infants were required to look at the event for a minimum of 2 continuous seconds in order for the look to be counted as a trial. This requirement ensured that infants attended to the event long enough to view the hand place the object in its spatial relationship to the second object. A trial continued until an infant looked away for more than 1 continuous second or until the 30s trial ended. Immediately following the end of a trial, the chiming green attention-getter reappeared to redirect the infant's attention to the monitor before the start of the next trial.

As the start of the experiment, infants viewed a warm-up trial that presented a stuffed pink pig being moved, first to the right and then to the left, by a hand. Following this warm-up trial, the habituation phase of the experiment began. The four events viewed during habituation were presented in a random order within blocks of four habituation trials with the restriction that no more than two consecutive trials of the same event were presented. The habituation phase of the experiment continued until infants’ looking time across a block of three consecutive habituation trials decreased to 50% of their looking time during the first three habituation trials. Once infants met this required criterion, the test phase of the experiment began. In the test, infants viewed the four test trials: familiar event, novel objects-familiar relationship event, familiar objects-novel relationship event, and novel objects-novel relationship event. Inter-observer reliability was determined by computing correlations of on-line and off-line looking times for 10 randomly chosen infants. These correlations ranged from .979 to .999 with an average of .992.

Results

The first analysis examined whether infants demonstrated a reliable decrease in looking time to the habituation events from the beginning of the habituation phase to the beginning of the test phase. Thus, infant's looking times were examined in a 2 Sex (females vs. males) x 3 Condition (containment vs. support vs. tight-fit) x 2 Trials (average of the first three habituation trials vs. familiar test trial) mixed-model analysis of variance (ANOVA).[3] The analysis did not yield any significant main effects or interactions with Sex or Condition, but did yield a significant main effect for Trials, $F(1, 30) = 62.91$, $p < .001$. Infants fixated significantly longer during the average of the first three habituation trials ($M = 16.80$ s, $SD = 7.03$ s) than during the familiar test trial ($M = 7.01$ s, $SD = 4.85$ s), which presented one of the events seen during habituation. Thus, infants provided reliable evidence that they habituated to the events presented during the habituation phase of the experiment and recognized one of these events as familiar when presented as a test trial.

[3] The average of the last three habituation trials was not used to determine whether infants had reliably habituated to the events because infants were required to meet a criterion of a 50% decrease in looking time during these three trials. Thus, infants' looking times to the last three habituation trials were low by definition of the habituation criterion. To determine more accurately then if infants recognized the habituation events as familiar by the end of the habituation phase, the familiar test trial is used instead in this analysis.

The next set of analyses addressed the pivotal question of the experiment. Do infants demonstrate a significant increase in looking time when there is a novel spatial relationship depicted in the test events or do infants dishabituate only when novel objects are presented? For infants in each condition, the means and standard deviations of their looking times to each of the test trials are presented in Table 2. Infants' looking times to the test trials were examined in a 2 Sex x 3 Condition x 2 Objects (familiar objects vs. novel objects) x 2 Spatial Relationship (familiar relationship vs. novel relationship) mixed-model ANOVA. This analysis yielded a significant main effect for Objects, F (1, 30) = 13.26, $p < .01$. Infants looked significantly longer at the two test trials that presented novel objects (M = 10.50 s, SD = 6.80 s) than at the test trials that presented familiar objects (M = 7.29 s, SD = 4.74 s). Thus, infants discriminated the novel pairs of objects in the test from the familiar pairs of objects, seen previously during habituation.

Insert Table 2 about here

The above analysis did not yield a main effect for Spatial Relationship, but did yield a significant interaction between Condition and Spatial Relationship, F (2, 30) = 3.46, $p < .05$. No other significant main effects or interactions were found in the analysis. The Condition x Spatial Relationship interaction is depicted in Figure 1 and results because infants in the containment condition demonstrated a very different response to the familiar versus novel relationship than the infants in the other conditions.

To examine the nature of the Condition x Spatial Relationship interaction, infants' looking times in each condition were analyzed separately. Sex was excluded as a factor in these analyses because no main effects or interactions with Sex had been found in the previous analyses and no sex differences were predicted a priori. For infants in the support condition, a 2 Objects x 2 Spatial Relationships ANOVA did not yield any significant main effects or interactions. As can be seen in the middle columns of Figure 1, infants did not demonstrate that they discriminated between the familiar and novel spatial relationship. Similarly, a 2 Objects x 2 Spatial Relationships ANOVA for infants in the tight-fit condition did not yield any significant main effect or interactions with Spatial Relationships, although the analysis did yield a significant main effect for Objects, F (1, 11) = 8.29, $p < .05$. Although infants in the tight-fit condition looked significantly longer at the novel (M = 10.50 s, SD = 6.90 s) than the familiar objects (M = 6.88 s, SD = 4.11 s), they did not provide any evidence that they discriminated between the familiar and novel relationship (see the right-hand columns of Figure 1).

Insert Figure 1 about here

For the infants in the containment condition, however, the 2 Objects x 2 Spatial Relationships mixed-model ANOVA yielded a main effect for Objects, F (1, 11) = 6.50, $p < .05$ and for Spatial Relationship, F (1, 11) = 6.21, $p < .05$. Infants looked significantly longer at the novel (M = 9.88 s, SD = 7.50 s) than at the familiar objects (M = 5.66 s, SD = 4.71 s). In addition, infants looked significantly longer at the events with a novel spatial relationship (M = 9.75 s, SD = 8.1 s) than at the events with the familiar spatial relationship (M = 5.79 s, SD = 3.81 s). This result can be seen in the two left-hand columns of Figure 1. Thus, these infants provide evidence that they discriminated reliably between the familiar (containment) and novel (support) spatial relationship. In addition, the analysis did not yield a significant Object x Spatial Relationship interaction, indicating that infants demonstrated the same pattern of looking to the novel versus familiar relationship when the objects were familiar and when they were novel, as shown in Figure 2. That is, infants looked significantly longer at the novel versus familiar relationship, both when the objects were familiar and when they were novel. Hence, infants generalized the containment relationship to a novel pair of objects and responded in a manner consistent with having formed a category of containment.

Insert Figure 2 about here

Several additional analyses were conducted to rule out the possibility that infants' responses to the test events were due to a preference for a particular pair of objects or for a particular type of event, such as a preference for support events over containment events. The first of these analyses explored whether infants demonstrated a preference for one of the pairs of objects viewed during the test trials. A 2 Sex x 3 Condition x 4 Object Pair (candle in vs. cup in vs. peg on vs. turtle on) ANOVA did yield a main effect for Object Pair, $F(3, 90) = 3.12$, $p < .05$, but also yielded a significant Object Pair x Condition interaction, $F(6, 90) = 3.20$, $p < .01$. The significant interaction indicates that infants' looking times to a particular pair of objects in the test trials depended on the condition to which they were assigned. Thus, across conditions, infants' did not demonstrate a consistent preference for a particular pair of objects. Rather, infants' response to a particular pair of objects in the test varied according to the events they viewed during habituation.

To explore whether the pattern of infants' looking times to the test events was guided by a priori preference for a type of spatial event, such as a preference for support over containment events, additional analyses were conducted. A priori preference for support events regardless of condition could provide an alternate explanation for the results. For example, infants in the containment condition might have looked longer at the support events relative to the containment events due to an existing overall interest in support pairs whereas infants habituated to support generalized to containment because of lower overall interest in the containment events. To ascertain whether this explanation might account for the results, infants' looking times to the test trials were analyzed in a 2 Sex x 3 Condition x 2 Spatial Event Type (average of the two containment test events vs. average of the two support test events). This analysis did not yield any significant main effects or interactions. Infants did not look significantly longer at the support (M = 9.67 s, SD = 5.11 s) than at the containment test events (M = 8.11 s, SD = 4.32 s), F (1,30) = 3.11, p = .09.

Although the comparison of infants' looking time to the two containment versus the two support test event did not yield a statistically significant difference, the analysis nevertheless raises the possibility that infants' may have had an existing preference for support over containment events. However, one shortcoming of this comparison is that the analysis makes it impossible to ascertain whether infants looked longer at a particular test event type, such as support, because of a priori preferences or because of the novelty of the events relative to the habituation events. As a result, this comparison is not the best measure of infants' a priori preferences for a particular type of event. Rather, two other analyses were conducted to test against a priori preferences.

A priori preference for support over containment events should be apparent during habituation. That is, infants in the support condition should demonstrate longer looking times to their habituation events than infants in the containment condition. A 2 Sex x 3 Condition x 1 Habituation Trial (average of the first three habituation trials) ANOVA did not yield any significant effects of condition, F (2, 30) = 1.02, p = ns, or gender, F (2, 30) = 2.38, p = ns, on infants' looking time to the first three habituation trials. Thus, during the initial trials of habituation, infants did not provide any evidence for a priori preference for support over containment events.

To rule out the possibility of a priori preference in the test trials, infants' looking times to the novel objects-novel relationship test trial was compared across conditions. This test trial was selected as a check against a priori preference because the trial presented a change in both the objects and the spatial relationship, thereby being equally novel to infants in all conditions regardless of their ability to respond to the spatial relationship in the event. A 2 Sex x 2 Condition x 1 Test Trial (novel objects-novel relationship test event) ANOVA did not yield a significant difference in looking time across conditions to the event presented as this test trial, F (2, 30) = .51, p = ns. No other main effects or interactions were significant in these analyses. Thus, similar to the previous analysis, the current analysis provided no indication that across conditions, infants preferred a particular type of spatial event, such as support, over the other type of spatial event (i.e., containment). When considered together, the analyses conducted to test for a priori preference indicate that infants responded to the test events on the basis of familiarity versus novelty rather than on the basis of a priori preferences for a particular pair of objects or a particular type of spatial relationship.

Discussion

At 9- to 11-months, infants provided reliable evidence that they discriminated between the familiar pairs of objects, seen during habituation, and the novel pairs of objects, seen for the first time during the test. Similarly, for those infants who had viewed the various examples of containment during habituation, these infants discriminated between spatial events with a containment relationship from events with a different relationship between the objects (i.e., support). In particular, infants responded to the containment relationship as more familiar than the novel relationship regardless of whether the objects depicting the relationship were familiar or novel. Thus, infants appeared to have formed a category of containment.

Although infants who viewed the support and tight-fit events during habituation easily discriminated between the familiar and novel pairs of objects, they provided no evidence that they were sensitive to the spatial relationship depicted between the various pairs of objects. When viewing a novel spatial relationship, infants did not look significantly longer at these events than at those with the familiar relationship. Thus, it seems to be the case that infants of 9 to 11 months can easily discriminate among different pairs of objects, can form a category of containment relationships, but have difficulty recognizing the support and tight-fit relationships between objects.

The fact that infants formed a category of containment, but not of support or tight-fit indicates that, at least in the current context, infants of 9 to 11 months do not form spatial categories of all types of spatial relationships. Rather, there appears to be certain spatial relationships, such as containment, which are easier for infants to discriminate and categorize than others. In addition, the current results indicate that infants can form a spatial category consistent with the English semantic category of “in,” but do not form spatial categories consistent with the semantic categories of “on” and “kkita,” at least prior to the time that they begin to acquire spatial language. However, it may be that the ability to recognize and categorize support and tight-fit relationships is more cognitively demanding than the analogous task with containment relationships and appears at a later point in development. Although the 9- to 11-month-old infants had difficulty discriminating the support and tight-fit relationships from a different relationship and forming spatial categories of these relationships, perhaps 17- to 19-month-old infants are able to do so. Experiment 2 explores this possibility.

Experiment 2

The results of Experiment 1 demonstrated that the 9- to 11-month-old infants in each condition responded to a change in the objects pictured in the events. Yet, infants only responded reliably to a change in the spatial relationship when the change was from containment to the support relationship. In the current experiment, older infants between 17 and 19 months of age were tested on their ability to form a spatial category on the basis of containment, support, or tight-fit relationships. At 17 to 19 months, infants are in the age range in which children are reported to have begun to acquire spatial terms for the types of relationships depicted (e.g., Tomasello, 1987) and have language-specific semantic categories (Choi et al., 1999). Thus, the current experiment not only explores which spatial categories these older infants can form, but also whether these spatial categories are influenced by the semantic spatial categories of English.

An important point to be clarified is that English can describe the Korean category with the term, “tight” although the English term “tight” refers to a much broader array of events than the corresponding Korean term “kkita.” As Choi and Bowerman (1991) have noted, there is in fact no English word that expresses the same meaning as the Korean word “kkita,” which is the only word used to describe many spatial events in Korean. In addition, a tight-fitting dynamic spatial event is not grammatically marked in English. That is, English speakers are not required by the grammar of their language to express the tightness between two objects as a spatial term whereas Korean speakers are required to do so. Thus, one question tested in the current experiment is whether infants attend more to those spatial relationships that are grammatically marked in their language than those that are not.

Method

Participants. Thirty-six full-term 17- to 19-month-old infants, 18 females and 18 males, were recruited for the second experiment. Infants ranged in age from 16.5 to 19.5 months of age (M = 78.19 weeks, SD = 3.99 weeks, range = 72.14 – 84.57 weeks). Of those infants recruited, 30 were reported by their parents to comprehend the meaning of “in” and 30 were reported to comprehend the meaning of “on.” In addition, a number of these infants also were reported by their parents to produce “in” (N = 5) and “on” (N = 7). An additional 18 infants participated in the study but were not included in the final sample: 5 heard languages other than English in their home, 10 became inattentive or habituated so well that they walked away prior to the end of the experiment, and 4 did not meet the habituation criterion (described in Experiment 1). None of the infants recruited for the current study had participated in Experiment 1.

Stimuli, Apparatus, Design, and Procedure. The stimuli, apparatus, design, and procedure were identical to those described in Experiment 1. Inter-observer reliability was calculated by computing the correlation of on-line and off-line looking times for a random sample of 10 participants. These correlations ranged from .97 to .999, and averaged to be .994.

Results

As in Experiment 1, the first analysis examined whether the 17- to 19-month-old infants demonstrated a significant decrease in looking time to the events presented during habituation. Infants' looking times were examined in a 2 Sex x 3 Condition x 2 Trials (average of the first three habituation trials vs. familiar test trial) mixed-model ANOVA. This analysis yielded a main effect for Trials, F (1, 30) = 236.01, $p < .001$. Infants looked significantly less at the familiar test trial (M = 7.05 s, SD = 4.52 s) relative to the average of their looking time to the first three habituation trials (M = 23.08 s, SD = 6.39 s). Thus, infants provided reliable evidence that they habituated to the events seen throughout habituation.

The next analyses addressed whether the 17- to 19-month-old infants responded to either the change in objects or the change in spatial relationship presented in the test events. Presented in Table 3 are the means and standard deviations of infants' looking times, in each condition, to each test trial. Infants' looking times were examined in a 2 Sex x 3 Condition x 2 Objects (familiar object vs. novel object) x 2 Spatial Relationship (familiar relationship vs. novel relationship) mixed-model ANOVA. This analysis yielded a main effect for Objects, F (1, 30) = 11.96, $p < .01$, and for Spatial Relationship, F (1, 30) = 4.88, $p < .05$. Infants looked significantly longer at the test trials that presented novel pairs of objects (M = 14.47 s, SD = 8.33 s) than at those that presented familiar pairs of objects (M = 10.25 s, SD = 7.38 s). Similarly, infants looked reliably longer when a novel spatial relationship was depicted between the objects (M = 13.64 s, SD = 8.29 s) than when they viewed the familiar spatial relationship seen throughout habituation (M = 11.08 s, SD = 7.80 s). This latter result is presented in Figure 3.

Insert Figure 3 and Table 3 about here

The analysis also yielded several significant interactions. There was a significant Objects x Relationship interaction, F (1, 30) = 17.25, $p < .001$, due to the fact that infants' responses to the familiar versus the novel spatial relationship differed depending on whether the objects in the events were familiar or novel. In particular, infants looked longer at the novel than at the familiar relationship when the objects in the events were familiar, F (1, 30) = 16.88, $p < .001$, but did not do so when the objects were novel. However, there was also a significant three-way interaction among Objects, Spatial Relationship, and Condition, F (2, 30) = 4.30, $p < .05$, indicating that the Object x Relationship interaction varied across conditions. Consequently, the Object x Relationship interaction was examined separately by condition.

For infants in the containment condition, a 2 Spatial Relationship x 2 Objects ANOVA yielded a main effect for Objects, F (1, 11) = 16.60, $p < .01$, and for Spatial Relationship, F (1, 11) = 4.92, $p < .05$. The analysis did not yield a significant interaction between the type of objects and the spatial relationship. The top graph of Figure 4 clearly shows that infants demonstrated the same pattern of visual fixations to the familiar versus novel spatial relationship, regardless of whether the objects depicting the relationship were familiar or novel. Thus, infants discriminated the containment relationship from a novel spatial relationship with familiar objects. In addition, infants were also able to recognize containment as familiar relative to a novel spatial relationship (support) when depicted by a novel pair of objects. That is, infants in the containment condition responded to the events in a manner consistent with having formed a category of containment.

Insert Figure 4 about here

For infants in the support condition, the 2 Spatial Relationship x 2 Objects ANOVA did not yield any significant main effects or interactions. Nevertheless, as can be seen in the middle graph of Figure 4, infants in the support condition did appear to discriminate between the familiar and novel spatial relationships when the objects were familiar. A comparison of infants' looking times to the familiar versus novel relationship when the objects were familiar confirms that infants were able to discriminate the change in relationship reliably, $F(1,11) = 5.40$, $p < .05$. In contrast, when the objects were novel, the infants in the support condition did not look longer at the novel than at the familiar relationship.

For infants in the tight-fit condition, the 2 Spatial Relationship x 2 Objects ANOVA yielded a significant Spatial Relationship x Object interaction, $F(1, 11) = 35.97$, $p < .001$, but no significant main effects for Objects or Spatial Relationship. This interaction is presented in the bottom graph of Figure 4 and shows that infants looked significantly longer at the novel than at the familiar spatial relationship when the objects were familiar, F (1, 11) = 7.81, $p < .05$. In contrast, they did not look significantly differently at the familiar than at the novel relationship when the objects in the events were novel. Thus, infants in both the support and tight-fit conditions discriminated between the familiar and novel spatial relationship when the objects in the events were familiar, but not when they were novel.

A final set of analyses was conducted to explore whether infants' looking time to the test events could be explained by a prior preference for a particular pair of objects or for a particular type of event (e.g., support events). The first analysis examined infants' looking time to each pair of objects during the test trials. A 2 Sex x 3 Condition x 4 Object Pair (candle in vs. cup in vs. peg on vs. turtle on) ANOVA yielded a main effect for Object Pair, F (3, 90) = 8.58, $p < .01$, as well as a significant Object Pair x Condition interaction, F (6, 90) = 4.04, $p < .01$. The significant interaction between Object Pair and Condition indicates that infants did not demonstrate a clear preference for a particular pair of objects across all conditions. Rather, infants' looking times to the pairs of objects in the test trials depended on which object pair they had viewed during habituation.

To rule out the possibility of a priori preference for a particular type of spatial relationship, two additional analyses were conducted. In one analysis, infants' looking time to the average of the three habituation trials was examined in a 2 Sex x 3 Condition x 1 Habituation Trial (average of the first three habituation trials) ANOVA. This analysis did not yield any significant effects of condition, F (2, 30) = 1.73, $p = .19$, or gender, F (1, 30) = .25, $p = .62$, on infants' looking time during the first trials of habituation. Thus, infants in one condition did not demonstrate longer looking times, providing no evidence for a priori preference for a particular type of spatial event during habituation. Similarly, a 2 Sex x 3 Condition x 1 Test Trial (novel objects-novel relationship trial) did not yield any significant effects or interactions on infants' looking time to this test trial, including those with condition, F (2, 30) = .81, p = .45, or gender, F (1, 30) = .02, p = .88. Hence, similar to the younger infants, the 17- to 19-month-old infants provided no evidence of a priori preferences to a particular pair of objects or a particular type of event across conditions. Rather, infants' response to the test events was driven by their ability to respond to the familiarity or novelty of the objects and the spatial relationships.

Discussion

The results of Experiment 2 indicated that the 17- to 19-month-old infants reliably discriminated between the familiar and novel pairs of objects. Infants habituated to the different examples of containment also reliably discriminated between the familiar containment relationship and a different spatial relationship, both when the objects depicting the relationship were familiar and when they were novel. Thus, infants recognized the containment relationship as familiar independent of the objects depicting that relationship, indicating that infants had formed a category of containment. With the support and tight-fit relationships, infants also discriminated the familiar from a novel spatial relationship, but did so only when the objects depicting the relationship were familiar. These infants did not discriminate between the familiar and novel relationship when the objects were novel, suggesting that they did not generalize the familiar relationship to new instances and hence, had not formed a category of either support or tight-fit. Thus, similar to the results obtained in Experiment 1, the results of Experiment 2 indicate that 17- to 19-month-old infants can form a spatial category, but only when the relationship is containment.

Although infants did not form a spatial category of either the support or tight-fit spatial relationships, they nonetheless demonstrated that they were sensitive to a change in the spatial relationship between the familiar pair of objects. Given this pattern of findings, it appears as though infants attended to the habituation events on an individual basis, noticing a particular spatial relationship between a specific pair of objects but not recognizing that the spatial relationship was the same throughout habituation. Alternatively, it may be the case that infants were able to discriminate between the familiar and novel spatial relationship when each was presented by a novel pair of objects but their attention to the novel objects may have masked their response to the relationships.[4] From the current results, it is impossible to ascertain which possibility more accurately describes how infants were processing the familiar versus novel spatial relationship when novel objects depicted the relationships. The results nonetheless demonstrate that the infants were attending to more than the objects themselves and were sensitive to the fact that a different relationship was presented between a familiar pair of objects.

General Discussion

In the current experiments, infants of 9 to 11 months (Experiment 1) and 17 to 19 months (Experiment 2) were habituated to four examples of a particular spatial relationship, either containment, support, or tight-fit. Following habituation, the infants were tested with one of the familiar events seen during habituation, an event with familiar objects in a novel relationship, novel objects in the familiar habituation relationship, and novel objects in a novel relationship. The results of the experiments were expected to

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[4] We thank Steve Robertson for suggesting this possibility.

demonstrate not only whether infants can form a category of these spatial relationships, but also whether they can do so when complex objects and a changing referent object are presented.

The results indicate that, at both ages, infants who had habituated to the various examples of the containment relationship discriminated reliably between this relationship and another spatial relationship (i.e., support). In addition, infants did so regardless of whether familiar or novel objects depicted the relationship. Thus, infants appeared to have formed a spatial category of containment and were able to recognize this relationship independent of the objects that formed the relationship. However, neither the younger nor the older infants provided evidence that they had formed true categories of support or tight-fit. The 9- to 11-month-old infants who viewed the various examples of support or tight-fit relationships during habituation responded only to changes in the objects and did not respond to changes in the spatial relationship. In contrast, the 17- to 19-month-old infants in the support and tight-fit conditions did respond to a novel relationship between a familiar pair of objects, but did not when novel objects depicted the novel relationship. Thus, these older infants appeared to be sensitive to support and tight-fit relationships, at least with familiar objects, but they showed no evidence of forming an abstract category of either support or tight-fit that would apply to the relationship between novel as well as familiar objects.

One possible concern is whether the results for the infants in the containment condition might be explained by infants' use of simpler perceptual cues rather than their ability to recognize the containment relationship itself. In each containment event, the first object became partially, to almost completely, occluded when placed in the referent object, whereas the referent object remained totally visible. Consequently, infants may have dishabituated to events with a novel spatial relationship in the test because they noticed that in these events (e.g., the support event) the first object remained fully visible, but the referent object became occluded. However, if infants were only using changes in an object's occlusion to discriminate between habituation and test events, then both the younger and older infants who viewed the support events during habituation also should have been able to use these same progressive occlusion cues to form a category of support. However, that was not the case. Neither the younger nor older infants responded in a manner consistent with having a category of support, ruling out the possibility that infants in the containment condition discriminated among the events solely based on changes in the visibility of one of the objects.

An important point to emphasize is that the current results do not indicate that infants of 9 to 11 months or 17 to 19 months are unable under any circumstances to form a category of support or tight-fit, only that they do not do so within the current context. In contrast to previous studies in which simple forms, such as a dot or a diamond, were used in relation to the same referent object, the present studies presented infants with a variety of realistic objects in different spatial relationships with a variety of referent objects. Thus, the infants in the current studies were presented with a much more difficult task than the category tasks used in previous studies. If presented with either simpler objects, the same referent object, or perhaps both, infants might demonstrate the ability to form categories of support and tight-fit relationships. Likewise, infants might be able to form a category of support if they viewed static pictures of the relationship rather than dynamic events.[5] Nevertheless, the results provide clear evidence that infants were able to form a spatial category of containment in the current task, indicating that the task was not so difficult that infants were unable to form any category. Rather, the results of both experiments suggest that it is easier for infants to form a spatial category of containment than either support or tight-fit.

The results of the current studies are consistent with findings reported by Corrigan, Halpern, Aviezer, and Goldblatt (1981) who also found young children to recognize containment prior to support relationships. Similarly, Quinn found developmental changes in the types of spatial relationships that infants can recognize and group into a spatial category. Whereas 3- to 4-month-old can form a category of above and below relations (Quinn, 1994), they have difficulty doing so with the spatial relationship between (Quinn et al., 1999). However, by 6 to 7 months, infants can form this category (Quinn et al., 1999) in addition to a category of above and below (Quinn et al., 1996). Thus, certain spatial relationships are easier for infants to attend to and recognize than others. The current studies indicate that, during the first year, infants can also form a spatial category of containment in addition to above, below (Quinn, 1994; Quinn et al., 1996), between (Quinn et al., 1999; Quinn, 2000) and left versus right (Behl-Chadha & Eimas, 1995).

The current findings also suggest a developmental progression in the elements of the events infants were able to discriminate. In all conditions of Experiment 1, infants of 9 to 11 months responded reliably to changes in the familiar versus novel pair of objects presented. However, the containment relationship was the only relationship to which

[5] Only dynamic tight-fit events are described in Korean as “kkita.” Consequently, the presentation of static objects in a tight-fit relationship to one another would no longer be consistent with “kkita.”

infants of this age seemed to be sensitive. At 17 to 19 months, infants provided some evidence suggesting that they may also be sensitive to the support and tight-fit spatial relationships, if familiar objects were used. The developmental progression suggested by these results is that infants first learn to recognize the objects in a spatial event, then learn to recognize the spatial relationship between two specific objects, and finally learn to generalize a particular relationship to novel objects, recognizing the relationship independent of those objects.

Across a number of experiments, Quinn has found explicit evidence for the specific-to-abstract developmental progression suggested by the current results. As we mentioned previously, in his research, infants first recognized the spatial relationships of above, below or between prior to the age they generalized the relationship to novel forms and produced a spatial category. When viewed in relation to these findings, the results of Experiment 2 lend further support to the notion that infants first learn to recognize the spatial relationships between specific objects before they learn to generalize the relationship to novel objects. In light of this developmental pattern, it seems likely that if infants older than 17 to19 months were tested, they also would form an abstract category of support and possibly tight-fit relationships.

In addition to yielding results consistent with the specific-to-abstract developmental progression reported by Quinn (2000), the design of the current experiments allowed us to discover a developmental step not found in previous studies. When considering the support and tight-fit conditions in which developmental differences were found between younger and older infants, there also was evidence that infants first learn to discriminate between familiar and novel objects in a spatial event prior to discriminating between familiar and novel relationships between those objects. That is, for infants in the support and tight-fit conditions, the infants could respond to the objects at an earlier point in development than the spatial relationship that existed between those objects. These results raise the possibility that in general infants must first attend to individual objects before they can attend to the relationship between those objects. Such a developmental progression would be consistent with other experimental findings including reports by Oakes and Cohen (1990) and Cohen and Amsel (1998) that infants first attend to individual objects and their movements before attending to the causal relationship between those objects in simple launching events.

It was also interesting that the acquisition of spatial language by the 17- to 19-month-olds seemed to play little role in the infants' performance on the task. The one category that the older infants formed (i.e., containment), the younger infants also formed. In addition, the 17- to 19-month-old infants in the support condition did not form a category of support, even though 11 of the 12 infants in this condition were reported by their parents to comprehend "on" and 2 of these infants were reported to say the word.[6]. However, one limitation of the MacArthur language inventory used to obtain these reports is that parents were not given a specific context for the spatial terms listed. In fact, several of the parents incidentally reported that their infant understood the meaning of “on” as referring to turning on a light switch. While these infants comprehend “on” in relation to flipping a switch, they may not understand the meaning of “on” in relation to one object supporting another object. If this is the case, then it might explain why the 17-

[6] Even when the infant who was not reported to understand “on” was excluded from the data, the same pattern of results was obtained.

to 19-month-old infants did not form a category of support even though they were reported to understand the meaning of the corresponding spatial term.

Nevertheless, the current findings do not rule out the possibility that language can facilitate infants' ability to form particular types of spatial categories over others. Several experimental findings have demonstrated that the presence of a novel language label facilitates infants' abilities to form categories of objects (e.g., Balaban & Waxman, 1997; Waxman & Markow, 1995). The question then arises whether the presence of a particular language label also can facilitate infants’ ability to form categories of spatial relationships. Waxman and her colleagues have argued that novel words focus infants’ attention to objects specifically, allowing infants to attend to the underlying commonalities across a set of objects and as a result, form the corresponding category. Given that toddlers possess language-specific semantic spatial categories by about 18 months of age, it must be that linguistic input also facilitates the formation of spatial categories, at least for the purposes of linguistic expression. In fact, Bowerman (1989) has posited that children acquire language-specific semantic spatial categories by attending to the manner in which a particular word is used across different contexts and noting the commonalities that are present across these contexts. One direction for future experimental study is to examine the effect of linguistic input on infants’ spatial categorization. In addition, it is worth exploring whether this effect is unique to language. Roberts and Jacob (1991) found that instrumental music, as well as language labels, facilitated the ability of 15-month-old infants to form a category of animals. It may be that the facilitative effect of language on categorization may not be unique to language during the early stages of word learning, but may become so as infants’ linguistic abilities develop. Similarly, it may be that language facilitates the categorization of only objects at about 12 months of age, but later in development, at about 18 months of age, facilitates the categorization of spatial relationships in addition to objects.

Although the current experiments were designed, in part, to explore how infants' spatial categories related to the semantic categories of “in,” “on,” and “kkita,” the task used may have been too difficult for infants, at either age, to form spatial categories of support or tight-fit. Many of the events used in the current study, such as the peg in the block or the turtles stacked on one another and on a pole, were similar to the events used by Choi et al. (1999). The 18- to 23-month-old infants in their study were successful in matching verbal labels to the appropriate scenes, a task which arguably also requires infants to recognize each spatial relationship independent of the specific objects. However, the infants in Choi et al. were somewhat older than the 17- to 19-month-old infants tested in the present experiment. Clearly a topic for future research is to determine at what age older infants will also demonstrate the ability to categorize support and tight-fit relations using our habituation procedure.

Despite the inability of the results to speak directly to the issues related to semantic spatial categories, they do demonstrate that infants can form a category of containment and can do so when complex objects and changing referents are presented in the events. To our knowledge, these results are the first to demonstrate infant categorical representation of realistic, dynamic spatial events. Nevertheless, additional research is also needed to further explore why infants form particular spatial categories prior to others. From the current results, it remains unclear which perceptual cues infants may be using to form spatial categories and in what way those cues change with age and/or experience. Additional research is also needed to determine whether infants enter the current task with a particular spatial category in place or whether they learn the category throughout the course of the experiment. From the current results, it is not possible to know which of these possibilities is true. Gentner and Medina (1998) have suggested that the mere task of comparing different exemplars of the same category together in time leads to the extraction of the category. Hence, it is possible that infants learned the category of containment during habituation. On the other hand, infants may have already possessed this category prior to participating in the study. One approach in pinpointing the source of the containment category that infants formed in the current studies is to test Korean infants in the same task as the English-learning infants. If Korean infants demonstrate the ability to form a category of tight-fit, then this finding would suggest that infants are relying on their existing spatial categories when tested in the current task. This finding would also suggest that an infant's ambient language influences the types of spatial categories they form. Additional studies examining this possibility as well as those examining the perceptual factors that guide infants' categorization of spatial relationships must be conducted before we can begin to understand how infants learn to organize spatial relationships into categories and the factors that guide their ability to do so.

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This research was supported by NIH grant HD-23397 awarded to Leslie B. Cohen. We wish to express our thanks to Marina Nicollier and Melissa Villars for their invaluable help in subject recruitment and data collection. We also thank Melissa Bowerman, Paul Quinn, Henry Ricciuti and Steve Robertson for their useful comments on earlier versions of the manuscript.

The current research studies were submitted to the University of Texas at Austin by Marianella Casasola in partial fulfillment of the requirements for the doctoral degree in psychology.

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Table 1

The design of Experiment 1. The habituation events are presented in italics and the test events are presented in normal print. Events presented in bold print have a tight-fit between the objects.

	Condition		
	Containment	Support	Tight-fit
Habituation Event 1:	Animal in	Car on	**Candle in**
Habituation Event 2:	Car in	Cup on	**Lego on**
Habituation Event 3:	**Candle in**	**Round man on**	**Peg in**
Habituation Event 4:	**Peg in**	**Turtle on**	**Round man on**
Test Event 1: Familiar Objects-Familiar Rlshp.	**Candle in**	**Turtle on**	**Candle in**
Test Event 2: Novel Objects-Familiar Rlshp.	Cup in	Peg on	**Turtle on**
Test Event 3: Familiar Objects-Novel Rlshp.	Peg on	Cup in	Peg on
Test Event 4: Novel Objects – Novel Rlshp.	**Turtle on**	**Candle in**	Cup in

Table 2

The means and standard deviations of the 9- to 11-month-old infants' looking times to each test trial in each condition of Experiment 1.

	Condition		
	Containment	Support	Tight-fit
Habituation Event 1: Habituation Event 2: Habituation Event 3: Habituation Event 4:	Animal in Car in **Candle in** **Peg in**	Car on Cup on **Round man on** **Turtle on**	**Candle in** **Lego on** **Peg in** **Round man on**
Test Event 1: Familiar Objects-Familiar Rlshp.	**Candle in** M = 4.68s SD = 2.25s	**Turtle on** M = 9.57s SD = 5.96s	**Candle in** M = 6.68s SD = 4.66s
Test Event 2: Novel Objects-Familiar Rlshp.	Cup in M = 6.89s SD = 4.75s	Peg on M = 12.33s SD = 7.06s	**Turtle on** M = 9.52s SD = 5.60s
Test Event 3: Familiar Objects-Novel Rlshp.	Peg on M = 6.64s SD = 6.26s	Cup in M = 9.03s SD = 3.69s	Peg on M = 7.08s SD = 3.69s
Test Event 4: Novel Objects – Novel Rlshp.	**Turtle on** M = 12.86s SD = 8.70s	**Candle in** M = 9.90s SD = 5.13s	Cup in M = 11.48s SD = 8.14s

Table 3

The means and standard deviations of the 17- to 19-month-old infants' looking times to each test trial in each condition of Experiment 2.

	Condition		
	Containment	Support	Tight-fit
Habituation Event 1:	Animal in	Car on	**Candle in**
Habituation Event 2:	Car in	Cup on	**Lego on**
Habituation Event 3:	**Candle in**	**Round man on**	**Peg in**
Habituation Event 4:	**Peg in**	**Turtle on**	**Round man on**
Test Event 1: Familiar Objects-Familiar Rlshp.	**Candle in** M = 5.95s SD = 3.76s	**Turtle on** M = 7.23s SD = 4.66s	**Candle in** M = 7.97s SD = 5.18s
Test Event 2: Novel Objects-Familiar Rlshp.	Cup in M = 12.44s SD = 5.46s	Peg on M = 13.18s SD = 7.43s	**Turtle on** M = 19.73s SD = 10.02s
Test Event 3: Familiar Objects-Novel Rlshp.	Peg on M = 10.6s SD = 6.93s	Cup in M = 13.09s SD = 6.73s	Peg on M = 16.66s SD = 10.28s
Test Event 4: Novel Objects - Novel Rlshp.	**Turtle on** M = 16.00s SD = 8.27s	**Candle in** M = 11.46s SD = 8.52s	Cup in M = 14.01s SD = 8.50s

Figure Captions

Figure 1. The looking times with standard error of the 9- to 11-month-old infants in each condition of Experiment 1 to the familiar versus novel spatial relationship.

Figure 2. The looking times with standard error of the 9- to 11-month-old infants in the containment condition of Experiment 1 to the familiar versus novel spatial relationship, when the objects were familiar and when they were novel.

Figure 3. The looking times with standard error of the 17- to 19-month-old infants in each condition of Experiment 2 to the familiar versus novel spatial relationship.

Figure 4. The looking times with standard error of the 17- to 19-month-old infants in the containment condition (top graph), support condition (middle graph) and tight-fit condition (bottom graph) of Experiment 2 to the familiar versus novel relationship, when the objects were familiar and when they were novel.

Figure 1

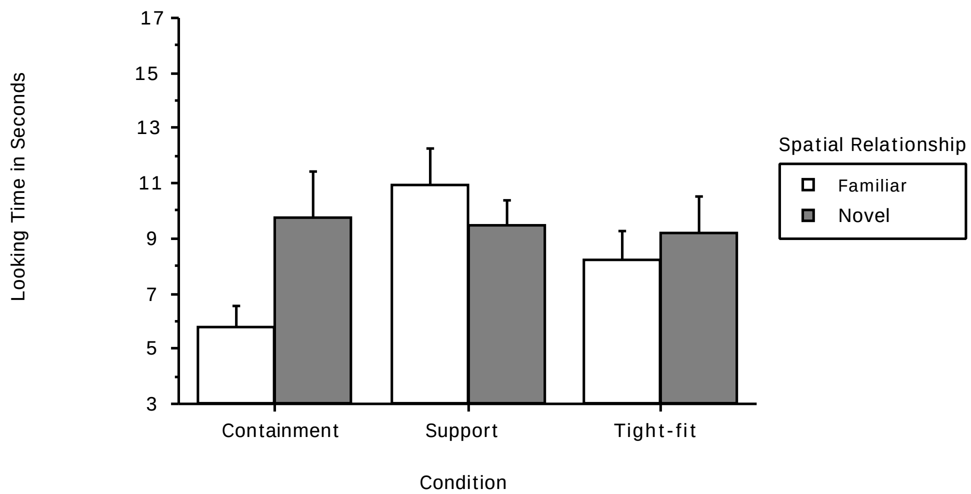

Looking Time in Seconds
17
15
13
11
9
7
5
3
Containment
Support
Tight-fit
Condition
Spatial Relationship
Familiar
Novel

Figure 2

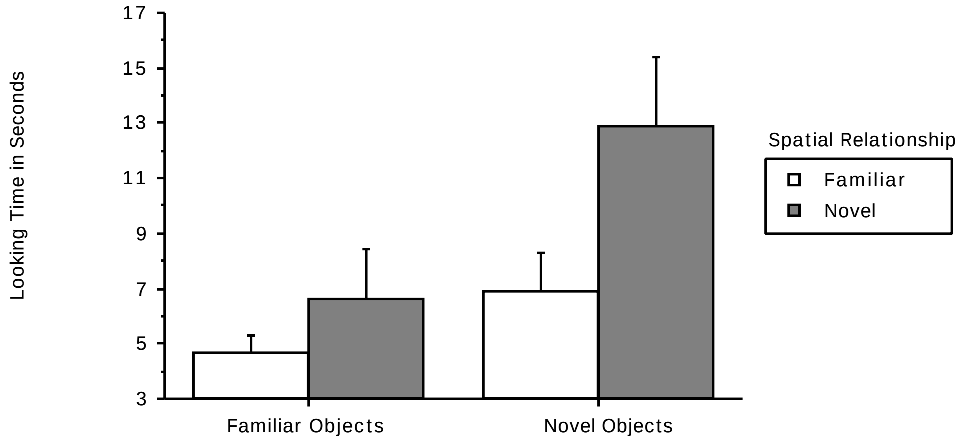
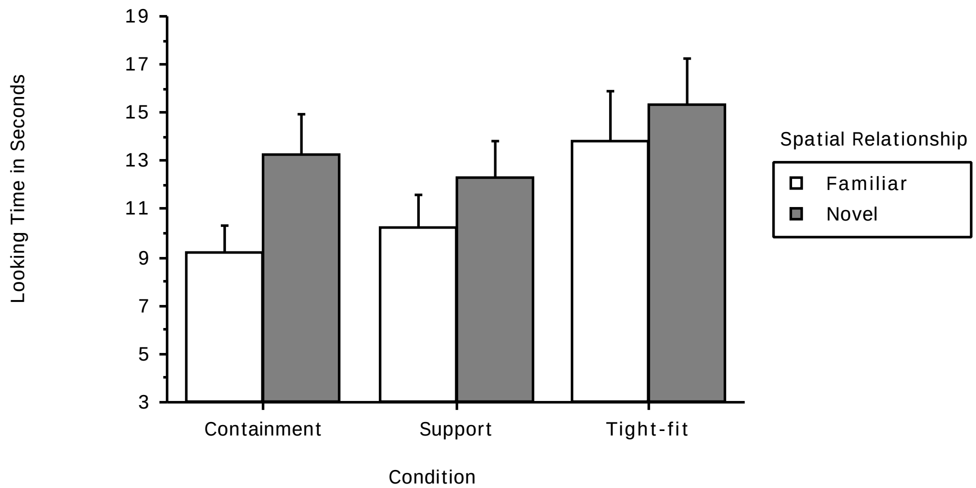

17
15
13
11
9
7
5
3
Looking Time in Seconds
Familiar Objects
Novel Objects
Spatial Relationship
Familiar
Novel

Figure 3


Looking Time in Seconds
19
17
15
13
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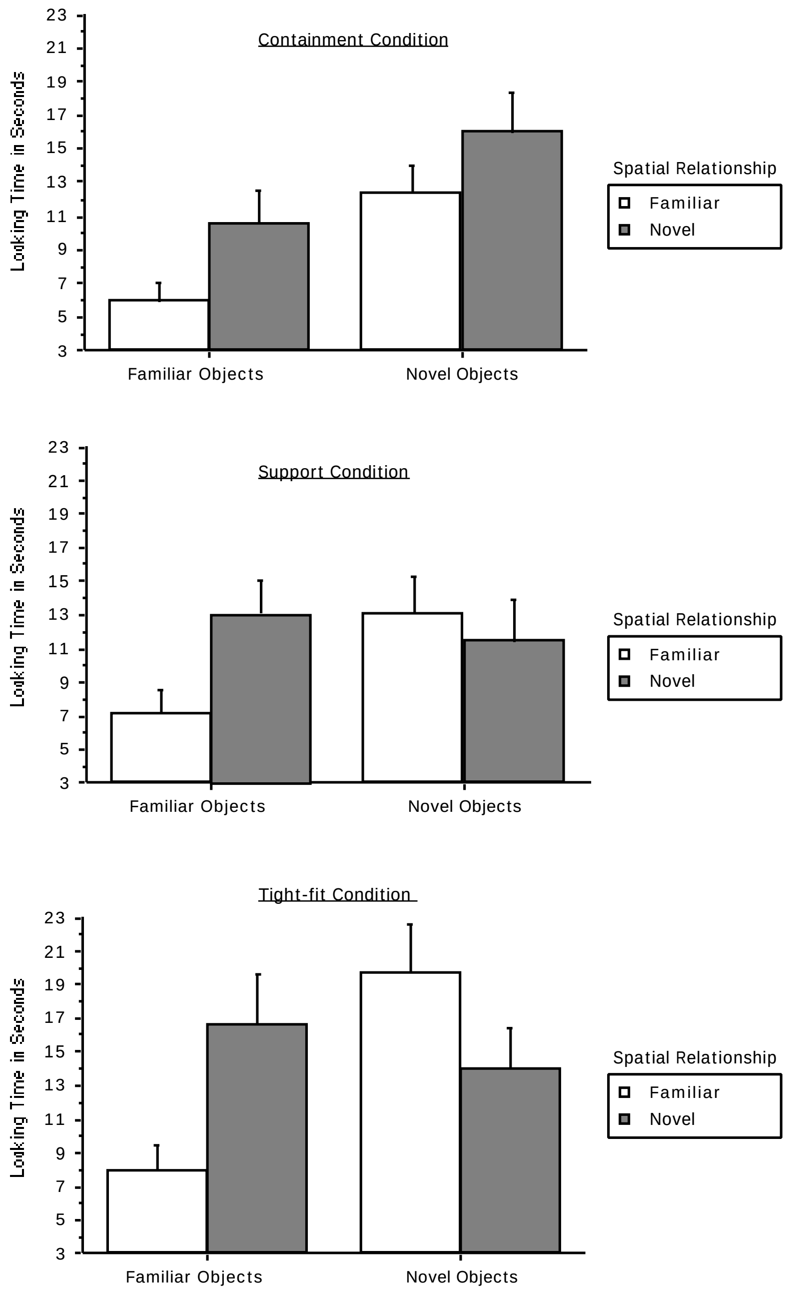
7
5
3
Containment
Support
Tight-fit
Condition
Spatial Relationship
Familiar
Novel

Figure 4



Containment Condition
Looking Time in Seconds
23
21
19
17
15
13
11
9
7
5
3
Familiar Objects
Novel Objects
Spatial Relationship
Familiar
Novel
Support Condition
Looking Time in Seconds
23
21
19
17
15
13
11
9
7
5
3
Familiar Objects
Novel Objects
Spatial Relationship
Familiar
Novel
Tight-fit Condition
Looking Time in Seconds
23
21
19
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9
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Familiar Objects
Novel Objects
Spatial Relationship
Familiar
Novel