Journal of Experimental Child Psychology 109 (2011) 109–122

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Does changing the reference frame affect infant categorization of the spatial relation BETWEEN?

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ARTICLE INFO

Article history:
Received 2 August 2010
Revised 1 October 2010
Available online 26 November 2010

Keywords:
Categorization
Spatial relations
Infants
Representation
Figure–ground
Target–referent

ABSTRACT

Past research has shown that variation in the target objects depicting a given spatial relation disrupts the formation of a category representation for that relation. In the current research, we asked whether changing the orientation of the referent frame depicting the spatial relation would also disrupt the formation of a category representation for that relation. Experiments 1 to 3 provided evidence that 6- and 7-month-olds formed a category representation for BETWEEN when a diamond shape was depicted in different locations between two vertical or horizontal reference bars during familiarization and in a novel location between the same orientation of bars during test. By contrast, in Experiment 4, same-age infants did not form a category representation for BETWEEN when the diamond shape was depicted between two vertical (or horizontal) bars during familiarization and between two horizontal (or vertical) bars during test. Moreover, in Experiment 5, 9- and 10-month-olds did form a category representation for BETWEEN when the orientation of the referent bars depicting the relation changed from familiarization to test. The findings suggest that the formation of category representations for spatial relations by infants is affected by changes to either target (figure) or referent (ground).

Introduction

Over the past 15 years, a literature has emerged on how preverbal infants represent spatial relation categories. This research suggests that infants over the first 9 to 10 months of life can form category representations for small-scale spatial relations such as ABOVE, BELOW, LEFT, RIGHT, and BETWEEN

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doi:10.1016/j.jecp.2010.10.001

(reviewed in Quinn, 2007). For example, 3- and 4-month-olds presented with stimuli in which a target (figure) shape (e.g., dot, diamond) appeared in discriminably different positions above or below a referent (ground) shape (i.e., a horizontal bar) will generalize looking time responsiveness to a stimulus in which the target shape has moved to a novel location in the familiarized relation but will display preferential responsiveness to a stimulus in which the target shape has moved to a location depicting the contrasting relation (Mash, Quinn, Dobson, & Narter, 1998; Quinn, 1994; Quinn, Cummins, Kase, Martin, & Weissman, 1996). Likewise, same-age infants presented with stimuli depicting the target shape in distinct locations to the left or right of a vertical referent bar will generalize responsiveness to a stimulus depicting the shape in a novel location on the same side of the bar but will display preferential responsiveness to a stimulus depicting the shape on the opposite side of the bar (Quinn, 2004; see also Gava, Valenza, & Turati, 2009, for corroborating evidence in newborns). Importantly, the infants are not simply encoding the arbitrary crossing of a shape from one side of the bar to the other because when the bar is diagonal and the changeover from the familiar category to the novel one involves a shape changing location from, for example, below left to above right of the bar, the infants do not respond differentially (Quinn, 2004). Taken together, the results suggest that young infants can represent the spatial relation category contrasts of ABOVE versus BELOW and LEFT versus RIGHT.

The spatial relational category contrasts of ABOVE versus BELOW and LEFT versus RIGHT have in common the requirement of encoding the location of a target shape in relation to a single referent shape. Quinn, Norris, Pasko, Schmader, and Mash (1999) examined whether 3- and 4-month-olds could also represent BETWEEN, a spatial relational category that requires encoding the location of a target in relation to two referents (Talmy, 2000). The experimental procedure was identical to that used by Quinn (1994), Quinn (2004), Quinn and colleagues (1996), and Mash and colleagues (1998) except that the infants were presented with a target diamond appearing in different locations between two referent bars (displayed as either columns or rows) and then were shown a test stimulus depicting the diamond in a new location between the bars paired with a test stimulus showing the diamond outside the bars (to either the left or right of the columns or above or below the rows). The 3- and 4-month-olds did not prefer either test stimulus; however, when Quinn and colleagues (1999) tested a group of 6- and 7-month-olds, the preference for the novel spatial relation was observed, indicating that the older infants had represented BETWEEN.

The fact that younger infants readily formed category representations for ABOVE versus BELOW and LEFT versus RIGHT, whereas only older infants provided evidence of a category representation for BETWEEN, suggests that representations that require encoding the relation between a target and a single referent are developmentally earlier than representations that require encoding the relation between a target and two referents. The infant data correspond with a developmental trend that has been reported in the literature on the encoding of spatial location information during childhood, where young children can represent targets in relation to single referents or landmarks earlier than they can encode targets in relation to multiple referents that define a local spatial framework or region (Huttenlocher & Newcombe, 1984). The developmental progression observed in the infant spatial categorization and child location encoding studies is also consistent with spatial language acquisition data showing that monoreferential spatial terms (e.g., *under*) are comprehended by children earlier than bireferential spatial terms (e.g., *between*) (Johnston & Slobin, 1979; Weist, Lyytinen, Wysocka, & Atanassova, 1997). The combination of findings suggests that the order of acquisition of spatial relational concepts in preverbal infants foreshadows the processing of those concepts in children and the order of acquisition of the relevant words in children's spatial lexicon.

An additional question that arises concerning the representation of spatial relations by preverbal infants is whether they are transferable beyond the instances depicting them. Clearly, to support the linguistic acquisition of spatial terms, representations for spatial relations would need to be generalizable across variation in objects. Adults observe many different objects in a variety of spatial relations and maintain their spatial concepts despite changes in the objects. For example, adults can be presented with A above B, and then subsequently with C above D, and recognize the equivalence of the ABOVE relation despite variation in the objects depicting the relation. In addition, children from around 2.5 years of age can encode the equivalence of spatial relations across at least some variation among the particular objects depicting the relations (Deloache, Kolstad, & Anderson, 1991; Uttal, Schreiber, & Deloache, 1995).

To examine the level of abstraction of young infants' representation of spatial relation information, 3- and 4-month-olds were administered an object variation version of the ABOVE versus BELOW categorization task (Quinn et al., 1996; Quinn, Polly, Furer, Dobson, & Narter, 2002). Four distinct shapes appeared above or below the bar during familiarization (e.g., arrow, diamond, dollar sign, dot), and in the preference test a novel shape (e.g., triangle) in the familiar spatial relation was paired with the same shape in a novel spatial relation. The young infants did not differentially attend to either test stimulus; however, older infants (6–7 months of age) did prefer the novel relation. The findings from the two age groups support the idea that category representations of spatial relations may initially be restricted to the objects depicting the relations but with development become more abstract so that various objects can be presented in the same relation, and the equivalence of the relation is preserved despite the variation.

Infants' representation of BETWEEN appears to undergo the same concrete-to-abstract (or specific-to-general) developmental shift that characterizes the representation of ABOVE and BELOW (Quinn, Adams, Kennedy, Shettler, & Wasnik, 2003).[1] However, the developmental time frame during which the shift occurs is from 6–7 months to 9–10 months of age rather than from 3–4 months to 6–7 months of age, as was observed for the representations of ABOVE and BELOW. This finding is of significance because it indicates that a broadly transferable abstraction ability does not have a rapid onset at 6–7 months of age, such that all category representations for spatial relations formed by that age could take on an abstract nature (cf. Mandler, 2000). Rather, the difference in developmental timing for the concrete-to-abstract developmental shift observed for ABOVE and BELOW, on the one hand, and BETWEEN, on the other, suggests that concrete representations for different spatial relations emerge at different points in developmental time depending on their ease of initial acquisition (e.g., landmark vs. framework representations) and that each representation undergoes its own period of development (approximating several months) from concrete to abstract. The concrete-to-abstract developmental trend in the representation of spatial relation information has also been observed in spatial categorization tasks involving realistic objects and dynamic stimulus presentations of containment and support relations from 10 to 18 months of age (Casasola, 2005; Casasola & Cohen, 2002).

The current experiments continue the inquiry into the degree of abstraction present in the representations for spatial relations by infants. In the studies to date, the variation presented to the infants has been in the target (figure) shapes. In the current study, which investigates the degree of abstraction present in the spatial relation BETWEEN, the variation is in the orientation of the referent (ground) shapes (i.e., the bars). This question is of interest because, on the one hand, there is evidence from both the visual and language domains in adults that attention is on the target or figure relative to the referent or ground during observation of and communication about spatial events (Gleitman, January, Nappa, & Trueswell, 2007; Vecera, Flevaris, & Filapek, 2004). If such findings were generalizable to infants, then that would suggest that changes to the target might be more disruptive than changes to the referent for processing of spatial relation information. On the other hand, the phenomenon of contextual cuing in adult visual attention suggests that attention cues off the global layout of items in a visual display (Chun & Jiang, 1998). It is also the case that referents tend to be physically larger than targets (Talmy, 2007), making them potentially more salient than targets. Both of these considerations would suggest that changes to the referents, like changes to the targets, will also disrupt infants' processing of spatial relation information. Experiments 1 to 3 identify the baseline conditions under which infants can form a representation for BETWEEN with a consistent orientation of the referent bars, and Experiments 4 and 5 examine how that representation is affected by a change in the orientation in the referent bars from familiarization to test.

[1] The question arises as to whether the concrete-to-abstract developmental shift can more aptly be described as a reweighting (Newcombe & Huttenlocher, 2000). Our view is that even if the developmental difference represents a reweighting of the concrete versus abstract information in the representation, that difference would still amount to a shift in the informational composition of the representation and, thereby, would constitute a developmental shift.

Experiment 1

In Experiment 1, 6- and 7-month-olds were tested for their ability to form a category representation for the spatial relation BETWEEN as it was depicted by a target diamond appearing in different locations between two referent bars oriented either vertically as columns or horizontally as rows. Whereas in Quinn and colleagues (1999) the diamond was depicted in different locations in either the top or bottom half of the area between the columns or in the left or right half of the area between the rows during familiarization, in the current study the diamond was depicted in the middle area between the vertical columns and the horizontal rows during familiarization, as shown in Fig. 1. The infants were subsequently tested with a novel exemplar of the familiarized spatial relation (i.e., the diamond appeared either above or below the familiarized locations between the columns or to the left or right of the familiarized locations between the rows) and a novel exemplar of a novel OUTSIDE relation (i.e., the diamond appeared either to the left or right of the columns or above or below the rows). Although Experiment 1 is a simple extension of Quinn and colleagues (1999), it (along with control Experiments 2 and 3) provides an internal baseline level of spatial categorization performance against which performance in Experiments 4 and 5 can be judged.

Method

Participants

Participants were 32 healthy, full-term 6- and 7-month-olds (18 girls and 14 boys) with a mean age of 193.38 days (*SD* = 12.16). An additional 2 infants were tested but did not complete the procedure due to fussiness. Participants in all experiments were predominantly Caucasian and from middle-class backgrounds. Each participant in each experiment took part in only that experiment and did not participate in any of the other experiments.

Stimuli

The stimuli were based on materials used by Quinn and colleagues (1999). They consisted of black elements on square white cards (17.7 cm or 30.1° per side) cut from Bainbridge No. 80 posterboard (Cranbury, NJ, USA). Each stimulus contained two 15.5-cm (26.9°) by 0.9-cm (1.7°) bars (each composed of a row of individual square elements [0.9 cm or 1.7° per side] spaced 0.6 cm [1.1°] apart) that were positioned either vertically or horizontally across the card. Each stimulus also contained a diamond shape that measured 0.9 cm (1.7°) per side.

For each infant, during familiarization the diamond appeared in each of four corners of an imaginary rectangle located in the middle of the area between the vertical columns or horizontal rows. The familiar diamond locations are shown in the left panels of Fig. 1, with each panel representing a composite of the four individual exemplars. The center-to-center distance between the top and bottom

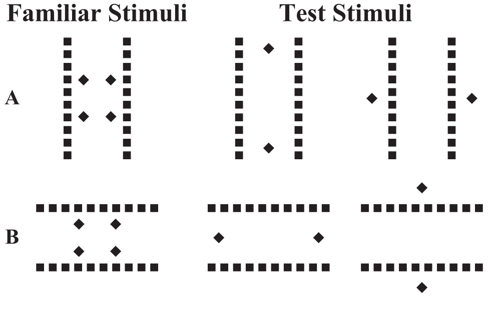

Fig. 1. From left to right: Familiarization stimuli (a composite of four exemplars), novel stimulus from the familiar category (a composite of two exemplars), and novel stimulus from the novel category (a composite of two exemplars). Referent bars are depicted as columns in Panel A and as rows in Panel B.

diamonds in the rectangle located between the columns (Fig. 1A) was 5.0 cm (9.3°), whereas the distance between the left- and right-side diamonds was 3.5 cm (6.5°). The center-to-center distance between the top and bottom diamonds in the rectangle located between the rows (Fig. 1B) was 3.5 cm (6.5°), whereas the distance between the left- and right-side diamonds was 5.0 cm (9.3°). The center-to-center distance between the diamonds closest to the bars and the bars themselves was 2.0 cm (3.8°). The diamond locations in the test stimuli are shown in the right panels of Fig. 1. The location of the novel exemplar from the familiar category was 6.4 cm (11.8°) down or up from the average of the familiar diamond locations between the columns (i.e., the center of the imaginary rectangle) in Fig. 1A or 6.4 cm (11.8°) left or right from the average of the familiar diamond locations between the rows in Fig. 1B. The location of the novel exemplar from the novel OUTSIDE category was 6.4 cm (11.8°) left or right of (Fig. 1A), or above or below (Fig. 1B), the imaginary rectangle's center.

Apparatus

All infants were tested in a visual preference apparatus modeled after the one described by Fagan (1970) and used in preceding studies in this same experimental series (e.g., Quinn et al., 2003). The apparatus is a large, three-sided gray viewing chamber that is on wheels. It has a hinged, gray display panel onto which were attached two compartments to hold the stimuli. The stimuli were illuminated by a fluorescent lamp that was shielded from infants' view. The center-to-center distance between compartments was 30.5 cm, and on all trials the display panel was situated approximately 30.5 cm in front of the infants. There was a 0.6-cm peephole located midway between the two display compartments that permitted an observer to record infants' visual fixations. A second peephole, 0.9 cm in diameter, was located directly below the first peephole and permitted a Pro Video CVC-120PH pinhole camera (Amityville, NY, USA) and a JVC video recorder (Wayne, NJ, USA) to record infants' gaze duration.

Procedure

All infants underwent the following general procedure. The infant was brought to the laboratory by a parent and seated in a reclining position on the parent's lap. There were two experimenters, both of whom were naive to the hypotheses under investigation. The first experimenter positioned the apparatus so that the midline of the infant's head was aligned with the midline of the display panel. The first experimenter also selected the appropriate stimuli as determined previously for the forthcoming trial, loaded them into the compartments of the display, and closed the panel, thereby exposing the stimuli to the infant. The parent was unable to see the stimuli.

During each trial, the first experimenter observed the infant through the small peephole and recorded visual fixations to the left and right stimuli by means of two 605 XE Accusplit electronic stopwatches (San Jose, CA, USA), one of which was held in each hand. The second experimenter timed the fixed duration of the trials and signaled the end of each trial. Between trials, the first experimenter opened the panel, changed stimuli, recorded infant looking times, and reclosed the panel. The first and second experimenters changed places for the test trials. The experimenter who presented the stimuli and measured infant fixations during familiarization now measured trial duration and signaled the end of each test trial, whereas the second experimenter presented the test stimuli and measured infant fixations. The second experimenter was always naive with respect to the information presented to the infant during familiarization. The two experimenters changed roles across infants.

Interobserver agreement, as determined by comparing the looking times measured by the experimenter using the center peephole and those of an additional naive observer measuring looking times offline from videotape records, was calculated for the preference test trials of 40 infants participating across the five experiments. The average level of agreement was 97.34% (SD = 2.24).

Half of the infants were familiarized and tested with the two bars depicted as columns (Fig. 1A), and half were familiarized and tested with the two bars depicted as rows (Fig. 1B). The diamond shape appeared in the four distinct locations between the bars (one location per exemplar) during familiarization trials (Fig. 1, left panels). The order of presentation of the different locations was randomly chosen for each infant. Each of the four familiarization trials was 15 s in duration. During test trials, the diamond shape in a novel location in the familiar spatial relation was paired with the diamond shape in a novel location in the novel OUTSIDE spatial relation (Fig. 1, right panels). There were two test trials, each 10 s in duration. The left–right positioning of the novel and familiar category stimuli was counterbalanced across infants on the first test trial and reversed on the second test trial.

Results and discussion

Familiarization trials

Individual looking times were summed over the left and right copies of the stimulus on each trial and then averaged across the first two trials and last two trials. Mean looking times are shown in Table 1. An analysis of variance (ANOVA: Trial Block [1–2 vs. 3–4] × Familiarization Condition [columns vs. rows]) of the individual looking time scores revealed a reliable effect only for trial block, $F(1, 30) = 5.73$, $p < .025$. No other effects were significant ($p > .20$ in each instance). Using the standard operational definition of habituation as a decline in responsiveness with repeated stimulation (e.g., Cohen & Gelber, 1975), the reliable decrement in looking time across familiarization trials indicates that infants in the column and row groups had habituated to the stimuli.

Preference test trials

Each infant's looking time to the novel category stimulus was divided by the looking time to both test stimuli and then converted to a percentage score. The mean novel category preference scores for the column and row familiarization conditions are shown in Table 1. Both preference scores were reliably different from the chance value of 50%, and the two scores were not different from each other, $t(30) = 0.99$, $p > .20$, two-tailed.

These results indicate that the infants formed a category representation for BETWEEN. The findings extend those of Quinn and colleagues (1999). In the earlier study, during familiarization, the diamond appeared in different locations in the top or bottom half of the area between the columns or in the left or right half of the area between the rows, whereas in the current study, the diamond appeared in the middle area between the columns and rows. The outcomes imply that the ability to form a category representation for BETWEEN is not dependent on the specific locations of the object presented between the bars and, along with Experiments 2 and 3, provide a baseline measure of infant categorization of BETWEEN.

Experiment 2

Given that categorization is defined as an equivalent response to instances from the same class that are discriminably different from one another, it is necessary to demonstrate that the instances of the familiarized category can be differentiated. Although within-category discrimination ability for exemplars of the BETWEEN relation was reported in Quinn and colleagues (1999), the location of the exemplars between the bars in the current study was different from what it was in the earlier study, and one cannot assume that the different regions of space occupied by the individual exemplars would be isotropic with respect to discriminability (van der Zee & Watson, 2005). Therefore, it becomes important to demonstrate within-category discrimination for the exemplars used in the current study.

Table 1
Mean fixation times during the familiarization trials and mean novel category preference scores during the test trials of Experiment 1.

Familiarization category	n	Fixation time (s)						
		Trials 1 and 2		Trials 3 and 4		Novelty preference (%)		
		M	SD	M	SD	M	SD	t[a]
Columns	16	6.19	1.37	5.45	1.93	63.59	6.81	7.98***
Rows	16	7.12	2.17	5.57	2.75	66.32	8.68	7.52***
Combined	32	6.65	1.85	5.51	2.34	64.96	8.04	10.52***

[a] t tests compared mean preference scores with chance performance of 50%.
*** $p < .001$, two-tailed.

Method

Participants

Participants were 32 healthy, full-term 6- and 7-month-olds (16 girls and 16 boys) with a mean age of 187.56 days ($SD = 8.99$). An additional 2 infants were tested but failed to complete the procedure due to fussiness.

Stimuli

The stimuli were the same as those used in Experiment 1.

Procedure

The within-category discrimination tests were designed on the basis of the categorization tests of Experiment 1. In Experiment 1, each infant was familiarized with four exemplars, each containing a diamond in one of four corners in the middle area between the columns or rows. The novel instance of the familiarized category shown during test trials contained a diamond shifted up or down from the familiarized diamond locations appearing between the columns or a diamond shifted left or right from the familiarized diamond locations appearing between the rows. In Experiment 2, each infant was tested for discrimination between two of the five exemplars used to represent the familiar category in a given familiarization and preference test condition. The pair of exemplars was randomly chosen for each infant, as was the member of the pair that would serve as the familiar stimulus. Familiarization consisted of a single 15-s familiarization trial during which the familiar stimulus was shown in both compartments of the display stage. Immediately after familiarization, the familiar stimulus was paired with the novel stimulus for two 10-s test trials. The left–right positioning of the novel stimulus was counterbalanced across infants on the first test trial and reversed on the second test trial. Half of the participants were tested with the diamond appearing in different locations between the columns, and the other half were tested with the diamond appearing in different locations between the rows.

Results and discussion

Familiarization trials

Individual looking times were summed over the left and right copies of the stimulus on the familiarization trial and then averaged across infants. Mean looking times in the column and row conditions are shown in Table 2. The difference was not significant, $t(30) = 0.90$, $p > .20$, two-tailed.

Preference test trials

Each infant's looking time to the novel stimulus was divided by the looking time to both test stimuli and then converted to a percentage score. Mean preference scores for the novel stimulus for the column and row familiarization conditions are shown in Table 2. The means were well above 50%, and t tests comparing the mean scores with chance revealed both to be statistically reliable. In addition, a t test showed that the two mean scores were not significantly different from each other,

Table 2
Mean fixation times during the familiarization trial and mean novelty preference scores during the preference test trials of Experiment 2.

Familiarization stimulus	Familiarization trial (s)		Novelty preference (%)		
	M	*SD*	*M*	*SD*	t^{a}
Columns	6.36	2.68	63.48	19.13	2.82*
Rows	7.34	3.44	63.15	11.86	4.44***
Combined	6.85	3.19	63.31	15.66	4.81***

[a] t for mean versus chance.
* $p < .02$, two-tailed.
*** $p < .001$, two-tailed.

$t(30) = 0.06$, $p > .20$, two-tailed. Infants familiarized with a stimulus depicting the diamond between the bars (either columns or rows) preferred a stimulus depicting the diamond in a novel position between the bars. These results indicate that the 6- and 7-month-olds were able to discriminate the exemplars from within the BETWEEN category and that the novel category preference scores observed in Experiment 1 were unlikely to have arisen from within-category discrimination failure.

Experiment 3

Experiment 3 was designed to examine one other alternative interpretation of the results of Experiment 1, namely, that the novel category preferences might have occurred because of an a priori preference for the test stimuli in which the object appeared outside the bars. Although no such preference was observed in prior studies (Quinn et al., 1999; Quinn et al., 2003), the object was located in different positions in the current study. Thus, a group of 6- and 7-month-olds was presented with the test stimulus pairs used in Experiment 1 but without familiarization. Each infant was given two 10-s test trials that paired a stimulus depicting a shape between the bars with a stimulus depicting the same shape outside the bars.

Method

Participants

Participants were 32 healthy, full-term 6- and 7-month-olds (18 girls and 14 boys) with a mean age of 188.06 days ($SD = 8.37$). An additional 1 infant was tested but was excluded from the data analysis because of failure to compare the test stimuli.

Stimuli

The stimuli were the test stimuli used in Experiment 1.

Procedure

Each infant received two 10-s trials during which a between-bars stimulus was paired with an outside-bars stimulus. The test stimulus pairings were the same ones presented to the 32 infants in Experiment 1. These pairings are shown in the right panels of Figs. 1A and B. For this experiment, the second experimenter did not participate other than to time the fixed duration of the trials and signal when a trial was to end.

Results and discussion

A preference score for the outside-bars stimulus was determined for each infant by dividing the time that this stimulus was observed by the total looking time to both stimuli. The score was then converted into a percentage. Mean preference scores for the column and row conditions were 50.22 ($SD = 15.76$) and 46.40 ($SD = 11.77$), respectively. Neither of the mean scores differed reliably from chance, $t(15) = 0.06$ and -1.22, respectively, $p > .20$, two-tailed. The scores did not differ reliably from each other, $t(30) = 0.77$, $p > .20$, two-tailed. The combined mean of 48.31 ($SD = 13.82$) also did not differ significantly from chance, $t(31) = -0.69$, $p > .20$, two-tailed. These results provide evidence that the 6- and 7-month-olds did not have an a priori preference for stimuli that depicted a shape outside the bars. Thus, the reliable novel category preference scores observed in Experiment 1 were not likely to have occurred because of a spontaneous preference for the novel category test stimuli.

Experiment 4

Experiment 4 investigated whether 6- and 7-month-olds would form a category representation for BETWEEN when the reference bars used to depict the relation changed in orientation from familiarization to preference test. Infants were familiarized and preference tested as in Experiment 1; however, in this instance, those infants familiarized with columns were tested with rows, whereas those infants familiarized with rows were tested with columns (see Fig. 2). If the infants form a category representation for BETWEEN irrespective of the orientation of the referent bars, then they should prefer the novel spatial relation. Alternatively, if the infants do not form a category representation for BETWEEN that generalizes to changes in the orientation of the referent bars, then one would not expect a preference for either test stimulus.

Method

Participants

Participants were 32 healthy, full-term 6- and 7-month-olds (17 girls and 15 boys) with a mean age of 193.38 days (SD = 12.16). An additional 2 infants were tested but failed to complete the procedure due to fussiness.

Stimuli

The stimuli were those used in Experiment 1.

Procedure

The design of Experiment 4 matched that of Experiment 1 except that infants familiarized with columns were tested with rows and infants familiarized with rows were tested with columns (Fig. 2).

Results and discussion

Familiarization trials

Mean looking times for the column and row familiarization conditions are shown in Table 3. An ANOVA (Trial Block × Familiarization Condition) of the individual scores revealed only a significant effect of trial block, $F(1, 30) = 14.55$, $p < .001$, indicating an overall decline in looking time from the first half of familiarization to the second half. The reliable decrement in looking time indicates that infants in both groups had habituated to the stimuli. Moreover, the average looking time per familiarization trial in Experiment 4 (M = 5.90 s, SD = 2.53) was not reliably different from that in Experiment 1 (M = 6.08 s, SD = 1.62), $t(62) = -0.34$, $p > .20$, two-tailed. This latter result indicates that any performance differences observed on the preference test trials of Experiments 1 and 4 cannot easily be attributed to differential looking time during familiarization of the two experiments.

Preference test trials

Mean novel category preference scores for the column and row familiarization conditions are shown in Table 3. Neither preference score was reliably different from the chance value of 50%, nor were the two scores different from each other, $t(30) = 0.27$, $p > .20$, two-tailed. These results indicate

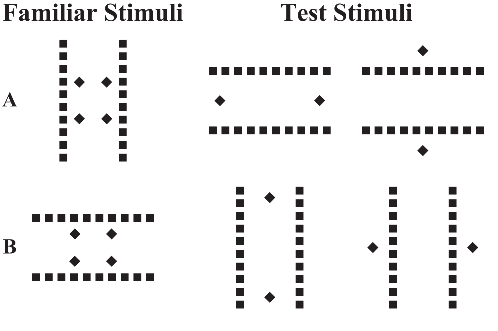

Fig. 2. From left to right: Familiarization stimuli (a composite of four exemplars), novel stimulus from the familiar category (a composite of two exemplars), and novel stimulus from the novel category (a composite of two exemplars). Panel A depicts the condition in which infants were familiarized with columns and tested with rows, whereas Panel B displays the condition in which infants were familiarized with rows and tested with columns.

Table 3
Mean fixation times during the familiarization trials and mean novel category preference scores during the test trials of Experiment 4.

Familiarization category	*n*	Fixation time (s)						
		Trials 1 and 2		Trials 3 and 4		Novelty preference (%)		
		M	*SD*	*M*	*SD*	*M*	*SD*	t[a]
Columns	16	7.30	3.14	5.99	3.29	54.17	15.64	1.07
Rows	16	6.08	2.40	4.22	1.81	52.71	15.33	0.71
Combined	32	6.69	2.82	5.10	2.76	53.44	15.25	1.28

[a] *t* for mean versus chance.

that the infants did not form a category representation for BETWEEN when the referent bars changed orientation from familiarization to test. Although null results need to be interpreted with caution, the findings imply that the category representations of 6- and 7-month-olds for BETWEEN demonstrated in Experiment 1 and in Quinn and colleagues (1999, 2003) were specific to the orientation of the referent bars depicting the relation.

Experiment 5

In Experiment 5, we attempted to determine when during development infants would form an abstract category representation for BETWEEN that was independent of the orientation of the referent bars depicting the relation. Therefore, Experiment 5 was conducted as a replication of Experiment 4, but with 9- and 10-month-olds. This age group was chosen because prior research had indicated that 9- and 10-month-olds, but not 6- and 7-month-olds, could form an abstract category representation for BETWEEN that was independent of the target objects depicting the relation (Quinn et al., 2003).

Method

Participants

Participants were 32 healthy, full-term 9- and 10-month-olds (18 girls and 14 boys) with a mean age = 277.69 days (*SD* = 12.57). An additional 3 infants were tested, but 1 did not complete the procedure due to fussiness and 2 were excluded from the data analysis because of failure to compare the test stimuli.

Stimuli

The stimuli were those used in Experiment 4.

Table 4
Mean fixation times during the familiarization trials and mean novel category preference scores during the test trials of Experiment 5.

Familiarization category	*n*	Fixation time (s)						
		Trials 1 and 2		Trials 3 and 4		Novelty preference (%)		
		M	*SD*	*M*	*SD*	*M*	*SD*	t[a]
Columns	16	5.65	2.79	4.96	1.20	64.81	17.92	3.31**
Rows	16	5.75	2.20	4.95	3.30	60.00	14.91	2.68*
Combined	32	5.70	2.47	4.96	2.44	62.41	16.40	4.28***

[a] *t* for mean versus chance.
* $p < .02$, two-tailed.
** $p < .01$, two-tailed.
*** $p < .001$, two-tailed.

Procedure

The procedure was the same as that used in Experiment 4.

Results and discussion

Familiarization trials

Mean looking times for the column and row familiarization conditions are shown in Table 4. An ANOVA (Trial Block × Familiarization Condition) of the individual scores revealed a significant effect only for trial block, $F(1, 30) = 5.71$, $p < .025$, indicating an overall decline in looking time from the first half of familiarization to the second half. The reliable decrement in looking time across familiarization trials indicates again that infants in both groups had habituated to the stimuli. It should also be noted that the average looking time per familiarization trial in Experiment 5 ($M = 5.33$ s, $SD = 2.29$) was not reliably different from that in Experiment 4 ($M = 5.90$ s, $SD = 2.53$), $t(62) = -1.06$, $p > .20$, two-tailed. This outcome indicates that any performance differences observed on the preference test trials of Experiments 4 and 5 are not likely due to differential looking time during familiarization of the two experiments.

Preference test trials

Mean novel category preference scores for the two familiarization conditions are shown in Table 4. As can be seen, t tests comparing the preference scores with 50% (chance) revealed the performance of infants in the column and row groups to be reliably above chance and not different from each other, $t(30) = 0.83$, $p > .20$, two-tailed. The findings indicate that by 9 to 10 months of age, infants can form an abstract category representation for BETWEEN that is independent of the orientation of the referent bars used to display the relation.

General discussion

Experiments 1 to 3 provided evidence that 6- and 7-month-olds could form a specific category representation for a target diamond appearing between two referent bars oriented as columns or rows. The findings extend the prior results of Quinn and colleagues (1999, 2003), who demonstrated that infants in the same age range could form a specific category representation for BETWEEN, albeit with different spacing arrangements between the target diamond and referent bars. Experiments 4 and 5 provide new information regarding the formation of category representations for spatial relations. In particular, they show that 9- and 10-month-olds, but not 6- and 7-month-olds, could form an abstract category representation for BETWEEN that was independent of the orientation of the referent bars depicting the relation.

Quinn and colleagues (2003) previously reported that a concrete-to-abstract (or specific-to-general) developmental trend in the same age range (6–10 months) was observed for the formation of a category representation for BETWEEN with variation in the target or figure objects depicting the relation. The current article provides evidence of a different manifestation of the concrete-to-abstract developmental trend with variation in the referent or ground objects depicting the relation. The results are noteworthy because studies from the domains of vision and language in adults indicate that attention is on the target or figure relative to the referent or ground during visual observation or linguistic communication of spatial events (Gleitman et al., 2007; Vecera et al., 2004). This portion of the adult literature would have suggested a pattern of outcomes across the infant studies in which changes to the target were shown to be more disruptive to maintaining a spatial category representation than were changes to the referent. However, the findings with the infants show that changes to either the target figure or the referent ground object can affect spatial category formation and development. These findings are consistent with visual attention data in adults showing that changes in the spatial layout of visual displays can disrupt processing of those displays (Chun & Jiang, 1998). They are also in accord with linguistic theory suggesting that the larger size of referent objects would increase their salience relative to smaller target objects (Talmy, 2007), thereby increasing the likelihood that changes to those referent objects would interfere with representations of target–referent relations.

The data from the current investigation are also interesting to consider in light of one previous investigation that investigated sensitivity to figure–ground relations in infants. Göksun, Hirsh-Pasek, and Golinkoff (2009) presented 7- to 9-month-olds and 10- to 12-month-olds with dynamic and static depictions of spatial motion events in a simple discrimination task. For example, the infants were familiarized with a video or snapshot of a man walking across the street and then were tested with a woman walking across the street (figure change) or the man walking across railroad tracks (ground change). The findings were that whereas sensitivity to the figure change was more readily in evidence earlier in development than was sensitivity to the ground change for the dynamic stimulus presentation, the reverse was true for the static stimulus presentation. Although this pattern of results is complex, the results from the current study are consistent with the more general conclusion from Göksun and colleagues' study, namely, that sensitivity to changes in both figure and ground aspects of spatial motion events are in evidence during the second half of the first year of life.

It is important to consider what mechanisms might underlie the concrete-to-abstract developmental shift, now observed with manipulations in both the target objects in previous studies (e.g., Quinn et al., 2003) and the orientation of the referent objects in the current study. With manipulation in the target objects depicting the BETWEEN relation in Quinn and colleagues (2003), at 6 to 7 months of age the representation was shown to be specific (i.e., only Object A could be related to Objects Y and Z in the same spatial representation), whereas at 9 to 10 months of age the representation was found to be more abstract and general (i.e., Objects A, B, C, D, and E could be related to Objects Y and Z in the same spatial representation). By the same reasoning and with the assumption that the change in the orientation of the referent bars caused them to be perceived as different objects, the current study suggests that at 6 to 7 months of age the representation is specific (i.e., Object A can be related to Objects W and X in the same spatial relation), whereas at 9 to 10 months of age the representation is more general (i.e., Object A can be related to Objects W, X, Y, and Z in the same spatial relation).

The question then becomes one of why spatial relation information in younger infants is specifically tied to the particular objects depicting the relation and not generalized to novel objects marking the same relation. Although the encoding of spatial relation information by young infants would lack abstraction, it would provide the concreteness necessary to support a spatial memory system that must remember the relative location of specific target objects in relation to particular referent or landmark objects. Thus, early in development, spatial categorization may serve primarily as an aid to spatial memory. By this view, the specific representations formed by younger infants are adaptive because they supply information in contexts where it is important to retain the particulars of the exemplars depicting the concepts, as is the case when remembering the locations of objects in relation to one another. This view also implies that the advantage of forming abstract concepts of spatial relations that are independent of specific objects may only come to be of consequence later in development, possibly when infants begin to locomote about their environment, encounter more and more objects in common spatial relations (Campos et al., 2000), and eventually learn lexical terms for the spatial relations that apply across objects.

This way of thinking about the concrete-to-abstract developmental trend observed during the preverbal period for infants' representation of spatial relations may also apply to similar developmental trends observed in infants' representation of causal relations and relational language acquisition. In the case of causal relations, Cohen and Oakes (1993) reported that when 10-month-olds initially begin to represent the causal relations between pairs of objects during the presentation of dynamic collision events, they do so in a way that allows them to tag which object was the "agent" and which was the "recipient". In the case of relational language acquisition, the mapping of novel verbs onto novel action events is at first conservative and done on a case-by-case basis (Tomasello, 1992). Just as infants do not readily transfer spatial or causal relations across objects, they also do not readily transfer structure across verbs that express action relations. Thus, in infants' learning of spatial and causal relations, as well as in infants' learning of verbs that express action relations, there is development from concrete item-based constructions to more general and abstract forms. That similar ontogenetic trends can be observed in all three domains suggests that they may be constrained by general principles of perception, learning, and development (Colunga & Smith, 2003).

In sum, the current experiments further our understanding of a concrete-to-abstract developmental trend in the formation of the category BETWEEN by demonstrating that it not only occurs for changes in the target objects as in Quinn and colleagues (2003) but also is observed for changes to the referent objects. The 6- and 7-month-olds were able to form a representation of BETWEEN when familiarized and tested with referents of the same orientation (i.e., vertical or horizontal). However, only older infants (9–10 months of age) seemed to form a more abstract representation of BETWEEN that generalized across changes in the orientation of the referent bars from familiarization to test.

Acknowledgments

This research was supported by National Institutes of Health (NIH) Grant HD-46526. We thank two anonymous reviewers for their comments on the original submission and Laurie Yarzab for assistance in testing infants and analyzing data.

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