Plain or Decorated? Object Visual Features Matter in Infant Spatial Categorization

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Abstract

The present study investigated infant spatial categorization of a support relation across differences in the perceptual features of the objects. Infants of 8 and 14 months ($N = 67$) were habituated to dynamic support events with objects that were plain and monochromatic or those that were embellished with decorations (e.g., polka dots, feathers). They were then tested with events that presented a novel pair of objects, a novel spatial relation (i.e., containment), or both. Infants, particularly those of 8 months, formed an abstract categorical representation of a support relation when habituated with the decorated but not plain objects. The results suggest that the perceptual features of objects can facilitate infants' categorization of spatial relations, at least in some learning settings and especially with younger infants.

Keywords: categorization, generalization, object features, spatial cognition

Plain or Decorated? Object Visual Features Matter in Infant Spatial Categorization

Early in development, young infants learn to form categorical representations of spatial relations, such as support, containment, left versus right, above versus below, between, and tight-fit versus loose-fit relations (e.g., Antell & Caron, 1985; Behl-Chadha & Eimas, 1995; Casasola & Cohen, 2002; Casasola, Cohen, & Chiarello, 2003; Gava, Valenza, & Turati, 2009; Hespos & Spelke, 2004; Quinn, 1994; Quinn, Adams, Kennedy, Shettler, & Wasnik, 2003; Quinn, Cummins, Kase, Martin, & Weissman, 1996). Spatial categorization is evident by 5 months of age, the youngest age at which infants have been shown to generalize a spatial relation to previously unseen objects (Casasola et al., 2003; Hespos & Spelke, 2004; Quinn et al., 2003). These spatial categories contribute to infants' understanding of how the objects in these events should interact (e.g., Baillargeon, Needham, & DeVos, 1992; Dan, Omori, & Tomiyasu, 2000; Hespos & Baillargeon, 2001). Yet, our understanding of *how* infants learn to form these categorical representations remains limited. In the current study, we further examined the development of this ability, focusing on whether the type of objects used to depict a spatial relation influences infant spatial category formation.

Infant spatial categorization is a type of *relational* learning. Although spatial relations are perhaps more concrete (i.e., visually accessible) than other relations, categorization of spatial relations does overlap to some degree with other types of relational learning such as mathematical learning and analogical reasoning. In particular, spatial categorization (similar to mathematical learning and analogical reasoning) requires two key abilities. First, infants must look *beyond* the specific objects to note the type of spatial configuration between or among those objects (Gentner & Kurtz, 2005;

Gentner & Markman, 1997). In addition, they must be able to generalize the commonality in spatial relation to a novel exemplar (Quinn et al., 2003). This ability develops in stages, with infants first demonstrating the ability to discriminate changes in the spatial configuration of specific objects and only later demonstrating the ability to generalize from a specific instance or set of instances to a new example of that relation (Quinn et al., 1996). It is the ability to generalize from one set of examples of a spatial relation to a new one that is the focus of our present investigation.

There are only a few studies that offer insight into how infants overcome these two cognitive hurdles to form spatial categories. These insights emerge from studies that vary the spatial categorization task. For example, varying the number of exemplars presented during habituation affects infant spatial categorization. Whereas 14-month-old infants form spatial categories under more diverse conditions (Casasola & Park, 2013), 10-month-old infants form spatial categories when provided with at least four to six exemplars of a spatial relation (Casasola & Cohen, 2002; Casasola & Park, 2013). That is, younger infants require more exemplars to form a spatial category, in line with results seen in infants' object categorization studies (Bomba & Siqueland, 1983; Needham, Dueker, & Lockhead, 2005; Quinn & Bhatt, 2005). The contrasting spatial relation also matters. When contrasted with a support relation, infants formed the category of containment, but not when contrasted with an occlusion relation (Rigney & Wang, 2015). Providing spatial language during habituation also facilitates spatial categorization in older infants (Casasola, 2005a; Casasola & Bhagwat, 2007), possibly because spatial labels direct infant attention to the spatial relations and facilitate abstraction.

In addition, the use of simple objects may facilitate generalizing a spatial relation to a new set of objects. Hespos and Spelke (2004) showed that 5-month-old infants generalized a tight-fit spatial relation to a new example of this relation following familiarization to a single exemplar. This result contrasts with previous work in which infants of 10 and 18 months did not generalize the tight-fit relation to a new instance (Casasola & Cohen, 2002), despite viewing four exemplars of the tight-fit relation. Two notable differences across the two studies may account for the discrepant results. First, Hespos and Spelke used perceptually plain objects, a simple cylinder and a cylindrical container, to depict the tight-fit relation, whereas Casasola and colleagues used toys and everyday objects such as a cookie cutter and a basket that were more perceptually complex. In addition, Hespos and Spelke presented live events whereas Casasola and colleagues presented videotaped versions of the events. Possibly, the use of simple objects, presented as live events, rather than toys presented on video, explains why younger infants succeeded in forming a spatial category that older infants did not. Using the contrast between these two studies as a backdrop, we focused on the issue of whether the perceptual features of the objects in events shape infants' spatial categorization in the present study.

Although the role of the perceptual features of objects is a question that has not been examined in infants, there is a rich literature with children's relational learning (of which infant spatial categorization can be argued to be one example) that has compared young children's relational learning across the sparseness versus richness of surface features of the objects employed to depict a relation. In some cases, perceptually simple objects have enhanced relational learning while more perceptually complex ones created

a more challenging task (Kaminski & Sloutsky, 2009, 2010; Kaminski, Sloutsky, & Heckler, 2006; Rattermann, Gentner, & DeLoache, 1990; Son, Smith, & Goldstone, 2011). In one study, Rattermann, Gentner, and DeLoache (1990) examined children's ability to perform relational matching (e.g., matching the relative size among three objects demonstrating a monotonic increase or decrease in size) when the relational match was pitted against the object match. They found that young children made more relational choices (focusing on relative size) when the objects were perceptually simple and identical to each other (three clay pots that differed from each other only in size) than when they were perceptually rich and diverse from each other (a toy house, a toy car, and a decorative mug, each also varying in size). Similarly, young children transferred an ABA or BAA relation better when it was depicted with shapes such as three triangles than with perceptually rich objects such as three dogs (Kaminski & Sloutsky, 2010; Son, Smith, & Goldstone, 2011). Also, the use of abstract geometric shapes was more effective than the use of perceptually rich and concrete objects in promoting transfer of mathematical rules for both children and adults (Kaminski, Sloutsky, & Heckler, 2006, 2008). Even when objects vary in color and pattern, relational performance can be disrupted. Elementary school students provided with brightly colored, patterned blocks in solving mathematical problems were more likely to be diverted from the relevant mathematical concepts compared to those who used monochromatic blocks (Uttal, Amaya, Maita, Hand, Cohen, O'Doherty, & DeLoache, 2013). Along similar lines, it has been shown that kindergarteners' attention is more distracted off task, with their learning gains being lower in visually complex, decorated classrooms than in visually sparse classroom environment (Fisher, Godwin, & Seltman, 2014).

Multiple underlying mechanisms have been proposed to explain the advantage of perceptually simple objects over more perceptually complex ones in transfer or relational learning. First, perceptually simplified objects that lack irrelevant features are posited to shortcut the learner's abstraction process and consequently promote generalization (Son, Smith, & Goldstone, 2008). Second, perceptually simplified objects have high portability in that they are more likely to be considered to refer to something else whereas the references of rich objects are highly limited to the specific objects presented (Kaminski, Sloutsky, & Heckler, 2008, 2010; Petersen & McNeil, 2013; Uttal et al., 2013). Third, perceptually complex objects have rich details that might make the objects more interesting in their own right, possibly shifting more cognitive resources to the objects themselves rather than the relation between the objects (e.g., Rattermann, Gentner, & DeLoache, 1990; also see DeLoache, 1987 and Uttal, Scudder, & DeLoache, 1997 for a similar discussion). This third proposal is in line with views that objects and relational information compete for cognitive resources, with the processing of one kind of information detracting from the processing of the other (e.g., Vecera & Farah, 1994).

Despite these findings, there is also evidence to show that in some cases, perceptually rich objects can provide an advantage over perceptually simpler ones in relational learning (e.g., Goldstone & Sakamoto, 2003; McNeil, Uttal, Jarvin, & Sternberg, 2009; Petersen & McNeil, 2013). For example, the use of sparkly pom-poms and multi-colored pinwheels facilitated young children's counting performance relative to solid-colored plastic disks and wooden pegs, demonstrating that rich objects facilitate children's performance when children have low established knowledge of the objects (Petersen & McNeil, 2013). Further, in a task of learning an abstract scientific principle

(e.g., competitive specialization of organisms) in a computer simulation, adults initially performed better with perceptually richer displays involving ants and fruit than with perceptually simpler displays involving dots and patches (Goldstone & Sakamoto, 2003). One reason for the advantage of perceptually rich objects over simpler ones could be that perceptually rich objects are more likely to attract learners' attention and thus, facilitate engagement with the task during the initial phase of learning (Petersen & McNeil, 2013). Although fewer in number relative to the many findings showing an advantage to perceptually simple objects, these results document that perceptual richness *per se* does not necessarily hamper children's ability to look beyond the objects.

These findings provide a starting point to consider how infants learn to form an abstract categorical representation of a spatial relation across different types of objects. In the present study, we examined if infants might benefit in their spatial categorization when shown perceptually simple objects (i.e., plain) or if instead, would benefit from more perceptually rich objects (i.e., decorated). On the one hand, the inclusion of simple objects in a spatial event may make it easier for infants to generalize a spatial relation to form the abstract spatial category, as suggested by comparing the findings reported by Hespos and Spelke (2004) and those reported by Casasola and Cohen (2002). The use of simple objects may also reduce the likelihood that infants pay more attention to the object surface features at the cost of attending to the spatial relation. If so, then infants who view spatial events with plain and perceptually simple objects will be more likely to form a spatial category than infants who view more perceptually complex objects.

Alternatively, it is possible that somewhat more perceptually rich objects, but nonetheless less complex than actual toys, may be ideal for forming the spatial category.

Because the perceptually rich objects are more engaging than the perceptually plain objects, infants may attend more to the spatial events with perceptually rich than plain objects. Furthermore, relative to plain objects, perceptually richer objects would include more perceptual changes in the surface features of the objects with changes in the spatial relation (e.g., occlusion of a portion of a pattern or feature), particularly for spatial events such as covering, containment, and occlusion events which often involve reduced visibility of the figure object. These perceptual changes in the appearance of an object when placed in a spatial relation could serve to heighten infants' attention to the spatial relation between the two objects and in this manner, bolster infants' ability to form a spatial category.

We tested infants on their ability to form a spatial category of support, a spatial relation that infants do not form easily (Casasola & Cohen, 2002). Although 5-month-old infants in Hespos and Spelke (2004) formed a tight-fit category, their ability to do so was less robust when familiarized with a loose-fit support relation. Thus, even in cases where infants can generalize a spatial relation, they show greater difficulty when the target relation is that of support. In addition, most previous studies that have manipulated the structure of the infant spatial categorization task have focused on infants' categorization of a support relation (Casasola, 2005b; Casasola & Park, 2013). We reasoned that infants' categorization of support may be more sensitive to differences in the perceptual features of the objects than other spatial relations, such as containment. We tested two age groups of infants, 8 and 14 months, to explore possible developmental changes in the impact of object complexity on infant spatial categorization. By 8 months infants attend to the patterns of objects in segregating objects (e.g., Needham & Baillargeon, 1997; Wilcox,

1999). By 14 months, infants form an abstract categorical representation of support in some but not all spatial tasks (Casasola, 2005b) and at 18 months, infants can still struggle to form this spatial category (Casasola & Cohen, 2002). Thus, examining infant spatial categorization of support was ideal as was testing infants at two ages, 8 and 14 months.

Consistent with previous studies with young children (e.g., Rattermann et al., 1990; Son et al., 2008), our stimuli were created to be at two perceptual levels: simple versus perceptually richer. Although the effect of objects' perceptual features has been examined on various learning tasks (e.g., Imai & Gentner, 1997; Sandhofer & Smith, 2004), to our knowledge, previous studies have not provided a single, unified operational definition of perceptually “simple” or “complex” objects. We combined the characteristics presented in the prior studies and operationally defined object perceptual complexity as based on three elements: 1. Overall object shape 2. Number of distinctive parts 3. Number of colors. Using this definition, a perceptually simple object in the present study had a simpler overall shape (e.g., a rectangular box), lacked distinctive parts, and was monochromatic. In contrast, a perceptually complex object had a more complex silhouette, and included both multiple parts and colors.

In sum, the results of the present study would address whether the inclusion of surface features of the objects in spatial events influences the spatial categorization of 8- and 14-month-old infants in a visual habituation task. Any differences that may emerge across our two conditions of objects would also provide insight into relational learning earlier in development.

Experiment 1

Experiment 1 was conducted to determine if 8- and 14-month-old infants form an abstract categorical representation of a support relation with perceptually simple versus richer objects. Infants were habituated to four distinct pairs of objects depicting a support relation. Infants were then tested with events that presented a novel pair of objects, a novel spatial relation (i.e., containment), or both. If infants form an abstract categorical representation for support, then they should look longer at the novel spatial relation not only when the objects are familiar but also when they are novel. Alternatively, if the infants do not form an abstract categorical representation of support, then one would not expect a longer looking to the novel spatial relation (especially when the objects are novel).

Method

Participants. Thirty-two infants of 14 months ($M = 14.0$ months, $SD = 0.31$ months, range = 13.5 – 14.5 months, 14 males and 18 females) and 35 infants of 8 months ($M = 8.1$ months, $SD = 0.40$ months, range = 7.3 – 8.8 months, 16 males and 19 females) participated in this study. They were recruited at the time of their birth from a local hospital and contacted for the study by a letter and subsequent phone call to their parents when they reached the appropriate age. All infants were full-term with no known visual or hearing problems. Most infants were Caucasian and were reported by their parents to hear English as their primary language. The majority of the parents were college-educated. Infants participated only once, at either the older or the younger age group.

An additional 10 14-month-olds and 12 8-month-olds were tested but removed from analysis for the following reasons: 10 failed to habituate, as defined by our

habituation criterion, and six infants did not complete the study due to fussiness; two infants were prompted by parents; and four infants were removed as outliers because their looking times deviated more than two standard deviations from the mean on the test trials (Two infants in the Plain condition and two infants in the Decorated condition; each was 14 months old).

Stimuli. Two sets of stimuli were created for the present study, one *Plain* and one *Decorated*. Each set contained six pairs of objects, and each pair of objects consisted of a $6 \times 6 \times 10$ cm small block used as the figure and a $23.5 \times 10.5 \times 8.5$ cm larger tissue box used as the referent object. The tissue box had an opening that allowed the figure to be inserted forming a containment relation, and had sufficient space on top for the figure to rest on it, forming a support relation.

The two sets differed from each other in their degree of decoration. As can be seen in Figure 1, the figures and referents in the *Plain* set were decorated with a single uniform color (either red, orange, blue, green, yellow, or purple) and lacked any additional decorations beyond their color. In contrast, the figures and referents in the *Decorated* set were brightly patterned (e.g., polka dots, waves, and checkerboard) and their surface features were enhanced with the addition of appendage features (e.g., robot arms, feathers, and antennas). While these objects were more colorful and had more distinctive parts than those in the *Plain* set, they had the same base colors as the objects in the *Decorated* set. Furthermore, each object within a pair had contrasting base colors (e.g., a yellow figure and a purple referent box) to ensure that infants could easily discriminate between the figure and referent objects.

A support event and a containment event were filmed with each pair of objects using a Canon ZR85 digital video camera. The dynamic events were then converted to QuickTime™ movies so that they could be edited and synchronized. Each event was 7 s in duration, and began with a figure and a referent placed side by side, with the figure to the right of the referent object. After 1 s, a hand entered the scene, grasped the figure, and placed it either on or in the referent box. Then the hand exited the scene and the final relation between the two objects was displayed for an additional 2 s. This 7-s event was looped five times without pauses to create a 35-s event video. No audio accompanied the videos. There were a total of 24 videos. These videos were used in this format for 14-month-old infants, but were shortened to better suit the attention span of the 8-month-old infants. Specifically, the first 1 s during which the figure and referent objects were standing still side-by-side was omitted for 8-month-old infants. This edit resulted in each event cycle being 6 s instead of 7 s, and the maximum length of each trial being 30 s rather than 35 s. This adaptation was made because pilot testing revealed that 8-month-old infants were more likely than 14-month-olds to look away too quickly to view the pivotal moment in which the figure object was placed in its spatial relation to the referent object. All other aspects of the stimuli such as the pace of movement were identical for the two age groups.

Plain condition

Habituation

A sky-blue box on an orange box, Orange on Blue, Yellow on Purple, and Green on Red			
Test

A sky-blue box on an orange box (Familiar objects in familiar relation), Yellow in Purple (Familiar objects in novel relation), Red on Green (Novel objects in familiar relation), and Purple in Yellow (Novel objects in novel relation)			

Decorated condition

Habituation

A sky-blue box on an orange box, Orange on Blue, Yellow on Purple, and Green on Red			
Test

A sky-blue box on an orange box (Familiar objects in familiar relation), Yellow in Purple (Familiar objects in novel relation), Red on Green (Novel objects in familiar relation), and Purple in Yellow (Novel objects in novel relation)			

Figure 1. Sample habituation and test events in the Plain and Decorated objects conditions.

Procedure. Infants were randomly assigned to either the *plain* or *decorated* condition. This assignment resulted in six males and 10 females in the plain condition and eight males and eight females in the decorated condition at 14 months; eight males and 10 females in the plain condition and eight males and nine females in the decorated condition at 8 months. Prior to the testing session, parents provided informed consent and completed a brief demographic survey. Once parents completed the survey, they and their infants were escorted to the infant testing room. Infants sat on their parent's lap facing a computer monitor. The parent was carefully instructed to avoid talking or pointing during the testing session. The experimenter then started the testing session in the adjoining room.

A Habit X 1.0 program (Cohen, Atkinson, & Chaput, 2000) was used to present the stimuli and record infants' looking times. A chiming green circle that expanded and contracted was used as the attention getter, which appeared prior to every trial to direct infants' attention to the monitor. As soon as the infant looked at the attention getter, the experimenter stopped the attention getter by pressing a key, and began the trial. During each trial, the experimenter, who was blind to the experimental phase and the specific events presented, recorded infant looking time by holding a key on the keyboard for as long as the infant was looking and releasing it when the infant looked away.

The visual habituation test consisted of three phases: pretest, habituation, and test. The pretest was aimed to familiarize infants with the test settings and the presentation of video stimulus on the monitor. During the pretest phase, infants viewed a stuffed animal (a pink pig) moved by a hand in a zigzag path until they lost interest and looked away. They could view the pretest event for 30 s as the maximum duration if they did not look

away. Following the pretest, the habituation phase began, during which infants repeatedly viewed four distinct dynamic videos, each with a distinct object pair and in which the figure object was placed in a support relation to the referent object. Which pairs of objects infants viewed during habituation was selected from the possible six pairs of objects such that each pair of objects occurred with approximately the same frequency across infants. The four habituation events were randomized in their presentation order by taking the 20 habituation trials, dividing them into 5 blocks of 4 trials, and within each block, presenting the four events in a random order. Infants viewed these four support events until their looking time across three consecutive trials decreased to 50% of their looking time across their first three habituation trials, or until they had viewed a maximum of 20 habituation trials. Therefore, the number of habituation trials that each infant viewed was subject-controlled, with a minimum of six trials and a maximum of 20 trials.

Once infants met the habituation criterion, or once they have viewed the maximum number of habituation trials, the test phase began. Infant viewed four test trials. One trial presented an event seen during habituation, referred to as the *familiar test event* because the objects and spatial relation had been viewed during habituation and were expected to be familiar to infants by the test phase. The remaining three test trials presented infants with events that were novel with respect to the objects, the spatial relation, or both. These four test events were presented in one of four orders created using a Latin square design. The orders were counterbalanced across infants and matched across conditions. After the testing session, all infants received a T-shirt, bib, or cup.

Inter-observer reliability was determined by calculating the correlation between online and offline looking times for 21 randomly selected infants (approximately 30% of the sample, 10 14-month-olds, 11 8-month-olds, half *plain*, half *decorated* condition). A second observer, blind to the study hypothesis, measured infants' offline looking times. The correlations between online and offline looking times ranged from .958 to .999 with an average correlation of .983 for the older infant group and .992 for the younger infant group.

An additional discrimination test was conducted to ensure that infants could discriminate among the support events used in the present study, a critical feature in demonstrating that they can respond to distinct exemplars as equivalent if they form the support category. A new sample of 11 infants of 8 months was habituated to a randomly selected support event. After habituation, they were presented with 2 test trials, presented in a random order: One presented the familiarized exemplar and the other presented a novel exemplar that was randomly selected from the support category for each infant. Five infants viewed plain objects during habituation and test, and six infants viewed decorated objects during habituation and test. Because one infant showed extreme looking times, we conducted a log10 transformation of infants' raw looking times. A 2 (object type: plain vs. decorated) $\times$ 2 (support event: familiar vs. novel) mixed-model analysis of variance (ANOVA) performed on the transformed looking times yielded only a significant main effect of support event, indicating that infants could indeed discriminate between the familiarized support event ($M = 3.90$ s, $SD = 1.93$ s) and a novel support event ($M = 4.84$ s, $SD = 2.30$ s), $F(1, 9) = 6.38$, $p < .05$, $\eta_p^2 = .42$. Neither the main effect of object type nor the object type $\times$ support event interaction was significant,

$F_s < 1$. That is, infants provided evidence of discriminating between two support events, regardless of the object type.

Results

Recall that the length of events was distinct for infants at each age, 35 s for the 14-month-olds and 30 s for the 8-month-olds. Using infants' raw looking times to the test events would have likely yielded a significant effect of age. Thus, to control for differences in trial length across the two age groups of infants, infants' raw looking times to each of the test events were converted to proportions of time spent looking during each trial. That is, for infants of 14 months, raw looking times were divided by 35, and by 30 for infants of 8 months.

Habituation phase. Although all infants in the final sample met the habituation criterion, we wanted to ensure that infants had indeed habituated to the events rather than reached the habituation criterion as an artifact. If infants truly habituated to the events, their looking time to the *familiar test event* (i.e., one of the habituation events presented in the test phase) was expected to be shorter than their looking time during the beginning phase of habituation. Thus, infants' looking time to the familiar test event was compared to their average looking time of the first three trials of habituation. Infants' looking times were submitted to a 2 (sex: males vs. females) $\times$ 2 (condition: plain vs. decorated) $\times$ 2 (trial: average of the first three habituation trials vs. the familiar test trial) $\times$ 2 (age: 8 vs. 14 months) mixed-model ANOVA. The analysis yielded a significant main effect of trial, $F(1, 58) = 123.20, p < .001, \eta_p^2 = .68$. Infants' looking time to the familiar test event ($M = .17, SD = .10$) was significantly shorter than their average looking time during the first three trials of habituation ($M = .48, SD = .21$), indicating that infants had indeed

habituated to the events. There was also a significant main effect of age, $F(1, 58) = 5.20$, $p < .05$, $\eta_p^2 = .08$. Older infants ($M = .54$, $SD = .20$) looked significantly longer than the younger infants ($M = .42$, $SD = .20$) during the first three habituation trials, $t(64) = 2.60$, $p < .05$.

Additionally, we examined the number of habituation trials that infants viewed. A 2 (age: 8 vs. 14 months) $\times 2$ (condition: plain vs. decorated) ANOVA performed on the number of habituation trials showed that infants viewed an average of 10.19 habituation trials ($SD = 4.56$), with no significant effects of age or condition. In sum, there was no evidence that infants' habituation pattern differed across the differences in perceptual features of the objects.

Test phase. We next examined infant looking times to the four test events to assess infants' formation of a categorical representation of support relations. If infants formed an abstract categorical representation of support, they were expected to look significantly longer at the novel (containment) than familiarized (support) relations, not only when the objects were familiar (seen during the habituation) but also when they were novel (seen for the first time in the test phase).

Infants' raw and proportion looking times to the four test events are presented in Table 1. Note that we again converted the raw looking times to proportion of time spent looking to control for differences in trial length for the two age groups of infants. A 2 (age: 8 vs. 14 months) $\times 2$ (condition: plain vs. decorated) $\times 2$ (objects: familiar vs. novel) $\times 2$ (spatial relation: familiar vs. novel) mixed-model ANOVA was performed on the proportions of total looking for each test trial. The data were collapsed across test order because our preliminary analysis did not reveal any significant effect of this factor

in infants' looking times to the test events. The ANOVA yielded a significant main effect of spatial relation, $F(1, 63) = 22.67, p < .001, \eta_p^2 = .27$, qualified by a significant spatial relation $\times$ condition interaction, $F(1, 63) = 5.75, p < .05, \eta_p^2 = .08$. That is, infants' looking times to the familiar versus novel spatial relation differed with plain versus decorated objects. There were no other significant effects.

Table 1

The raw looking times and proportions of looking time of infants to each of the four test events

			Familiar objects		Novel objects	
	Condition	Looking times (LT)	Familiar relation	Novel relation	Familiar relation	Novel relation
8 months	Plain	Raw LT	5.26 (2.26)	6.00 (3.45)	5.57 (3.51)	5.60 (2.70)
		Proportion LT	.18 (.08)	.20 (.11)	.19 (.12)	.19 (.09)
	Decorated	Raw LT	4.39 (3.23)	9.06 (7.39)	5.08 (3.34)	7.27 (4.50)
		Proportion LT	.15 (.11)	.30 (.25)	.17 (.11)	.24 (.15)
14 months	Plain	Raw LT	5.70 (3.02)	9.07 (9.16)	7.86 (5.84)	8.59 (4.36)
		Proportion LT	.16 (.09)	.26 (.26)	.22 (.17)	.25 (.12)
	Decorated	Raw LT	6.70 (4.74)	10.53 (8.25)	6.02 (3.29)	9.36 (5.73)
		Proportion LT	.19 (.14)	.30 (.24)	.17 (.09)	.27 (.16)

Figure 2. The mean proportion looking of 8- and 14-month-old infants to each of the four test events in the Plain condition (left graph) and the Decorated condition (right graph), age combined. Error bars represent 95% CIs.

To examine the nature of the spatial relation $\times$ condition interaction, we evaluated infants' formation of a support category in each condition separately. Because the omnibus ANOVA failed to yield any effect of infant age, the data were collapsed across this variable. The results can be seen in Figure 2. For infants in the plain condition, a 2 (objects: familiar vs. novel) $\times$ 2 (spatial relation: familiar vs. novel) repeated-measures ANOVA yielded no significant effects, including no significant effect of spatial relation, $F(1, 33) = 3.44$, *ns*. Thus, infants who viewed the plain objects looked similar durations to the familiar ($M = .19$, $SD = .08$) versus novel spatial relations ($M = .22$, $SD = .12$). In contrast, the same ANOVA performed on the looking times of infants in the decorated

condition yielded a highly significant main effect for spatial relation, $F(1, 32) = 20.86, p < .001, \eta_p^2 = .40$. As can be seen in the right graph of Figure 2, infants who viewed the decorated objects looked significantly longer at the novel ($M = .28, SD = .12$) than the familiarized relation ($M = .17, SD = .08$). Planned comparisons further showed that infants looked significantly longer at the novel ($M = .30, SD = .24$) than familiarized spatial relation ($M = .17, SD = .12$) when the objects were familiar, $t(32) = 3.30, p < .01$, and when they were novel ($M = .25, SD = .15$ for the novel relation, $M = .17, SD = .10$ for the familiar relation), $t(32) = 2.37, p < .05$ (two-tailed).

Although the omnibus ANOVA yielded no significant interaction involving age, infants' looking to the four test events nonetheless seemed to differ across age and condition (see Table 1). Given that previous research has documented developmental changes in infants' categorization of support relations (e.g., Casasola & Park, 2013), we analyzed the data from each infant age group separately. For infants of 8 months, a 2 (condition: plain vs. decorated) $\times$ 2 (objects: familiar vs. novel) $\times$ 2 (spatial relation: familiar vs. novel) mixed-model ANOVA revealed a significant main effect of spatial relation, $F(1, 33) = 10.26, p = .003, \eta_p^2 = .24$, which was qualified by a significant condition $\times$ spatial relation interaction, $F(1, 33) = 6.50, p = .016, \eta_p^2 = .17$. These younger infants looked similar durations at the familiar ($M = 5.41$ s, $SD = 1.95$ s) and novel ($M = 5.80$ s, $SD = 2.78$ s) relations when viewing the plain objects, whereas they looked significantly longer at the novel ($M = 8.17$ s, $SD = 4.14$ s) than the familiarized relation ($M = 4.74$ s, $SD = 2.23$ s) when viewing the decorated objects, $F(1, 16) = 15.19, p = .001, \eta_p^2 = .49$. For infants of 14 months, however, the same ANOVA yielded only a significant main effect of spatial relation, $F(1, 30) = 12.22, p = .001, \eta_p^2 = .29$, and no

significant condition $\times$ spatial relation interaction, $F < 1$, *ns*. The 14-month-old infants looked longer at the novel relation ($M = 9.39$ s, $SD = 4.49$ s) than the familiarized relation ($M = 6.57$ s, $SD = 3.02$ s), a pattern that did not vary with the type of objects presented in the spatial events.

Discussion

The performance of the infants in Experiment 1 suggests that infants formed an abstract categorical representation of support when this relation was depicted with objects with surface features, but this ability was not evident when the relation was presented with perceptually plain objects. The results also provide some evidence that surface features of the objects had a greater impact on the younger infants of 8 months than the older infants of 14 months, but not to such a degree as to yield significant interactions of age and condition. However, prior to drawing strong conclusions about the present results, we first sought to rule out an alternative explanation for the results. Infants may have an *a priori* preference for containment over support, a preference that is most evident when the relations are shown with rich objects, such as those used in our decorated condition. To rule out this possibility, we presented infants with containment and support events without first habituating them to a support relation. If infants look equally at the containment and support events in the absence of habituation, there would be no evidence that an *a priori* bias for containment accounts for the results of Experiment 1. Experiment 2 therefore presented 8- and 14-month-old infants with containment and support events involving rich objects. Critically, there was no habituation phase to a support relation and thus, the results of the second study would test for an *a priori* preference for containment events.

Experiment 2

Experiment 2 examined whether the increased looking to the containment events found in the decorated condition of Experiment 1 would be observed when infants view containment and support events without immediate repeated exposure to support events (i.e., no habituation to this relation). If the results from the first experiment emerged because of a preference for containment over support, when each was depicted by perceptually rich objects, then infants in the present experiment (who are not habituated to support events prior to viewing test events) should show the same pattern of results as infants of Experiment 1. To this end, a new sample of 8- and 14-month-old infants viewed the same four test events as infants in the decorated condition of Experiment 1, plus an additional containment and support event, for a total of six different events, three of which depicted a containment relation and three of which depicted a support relation.

Method

Participants. The participants were 16 infants: eight infants of 8 months (mean age = 8.1 months; $SD = 0.37$ months; range = 7.5 – 8.6 months) and eight infants of 14 months (mean age = 14.1 months; $SD = 0.47$ months; range = 13.5 – 14.5 months). One additional infant participated but did not complete the test because of fussiness. There were four males and four females in each age group.

Stimuli. The same twelve 30 s videos as those used in the *decorated* condition of Experiment 1 were used in this baseline preference study. Thus, there were six videos per type of spatial relation (i.e., support, containment), of which infants saw three videos of containment relations and three videos of support.

Procedure. All infants first received one pretest trial immediately followed by 12 test trials (there was no habituation phase). The stimulus and procedure of the pretest trial was the same as in Experiment 1 (i.e., a pink pig video). Then all infants were administered the 12 test trials consisting of two blocks of six trials, with the second block being a repeat of the first block. In each block, we presented the four test events that infants viewed in the actual experiment (Experiment 1), presented in the same order as in Experiment 1. Following these four events, infants viewed an additional two pairs of objects not seen previously, one IN and one ON event. One additional event from each spatial category was included to allow enough data to assess infants' baseline preferences for each type of relation. Test objects were carefully matched so that each object pair was presented only once to a given infant in a block of test trials. In addition, the test objects were presented with the same frequency across all infants. We also counterbalanced the presentation order of the IN and ON relations for the two extra events, and then changed the spatial relation of these events for other infants to control for any preferences for a specific pair of objects.

In sum, infants viewed three exemplars for each spatial relation and, in contrast to Experiment 1, did not view habituation events prior to viewing the test events. Presenting infants with distinct objects and counterbalancing the spatial relation depicted by each object pair across infants ensured that infants would not respond solely on the basis of the objects.

Results and Discussion

Infants' looking times were analyzed in a 2 (age: 8 vs. 14 months) $\times$ 2 (test block: first vs. second) $\times$ 2 (spatial relation: support vs. containment) $\times$ 3 (exemplars: first vs.

second vs. third) mixed-model ANOVA. The analysis did not yield any significant effects. Infants looked similar durations to the containment ($M = 9.24$ s, $SD = 3.51$ s) and support ($M = 9.25$ s, $SD = 4.64$ s) relations. In addition, when only the four events that matched the test events of Experiment 1 were included in the analysis, there were still no significant effects. These results indicate that infants do not have a strong preference for containment over support (nor vice versa) and do not support the possibility that infants in Experiment 1 responded to the test events based on a strong *a priori* bias for containment events.

General Discussion

The present study was designed to test whether the perceptual features of the objects depicting spatial relations impact infants' formation of an abstract categorical representation of a spatial relation. The combined results from Experiment 1 and 2 indicate that infants, especially those at 8 months, formed an abstract categorical representation of a support relation when the objects depicting the spatial relations included decorative features, but not when they were monochromatic and perceptually plain. To our knowledge, the present study is the first to manipulate the perceptual complexity of objects and document its impact on infant spatial categorization of a support relation.

Before we discuss how the current finding is connected to previous work, we address two possible alternative explanations for the results. First, one might raise the concern that, with the infant sitting on the parent's lap and the stimuli visible to the parent, the parents could have influenced infant performance (e.g., through heart rate change, subtle changes in posture, etc.). Although this concern is reasonable, parents

were not given opaque glasses in our study because in pilot work, older infants became distracted by them as they habituated to the events. We instead asked parents to remain neutral during the testing session and carefully instructed them to avoid directing their infants' attention in any way. There is no evidence to show a clear effect of parents on infant looking in the present task. The infant was sitting on the mother's lap, facing toward the monitor. The infant could not see whether the parent was looking at the monitor until the infant had looked away (i.e., lost interest in the stimulus shown) and turned his or her head backwards. Therefore, the infant could not refer to the parent's eye gaze as a guide for attending to the stimulus. Second, from our recordings of parents and infants during the experimental session, parents typically held their attention to the screen throughout the entire experimental session. Most parents continued to fixate on the screen even when their infant had looked away from the monitor and the attention getter was playing on the screen. Also, because events were only presented on a single monitor, the parent's posture or orienting response rarely changed during the 3- to 5-minute task. Lastly, in the present study, spatial categorization was seen with the decorated but not plain objects. It is difficult to imagine that this pattern of results reflects parents' response to the events because presumably, adults can form a spatial category of support whether the relation is depicted by plain or decorated objects. Thus, we posit that caregivers biasing their infants' looking time to the events did not seem to drive the present pattern of results.

Another question is whether the decorated condition had more variability from one object to another than in the plain condition and if this greater variability may have highlighted the constancy of the support relation across exemplars. Indeed, the presence

of decorative features may have increased the variation among exemplars in the decorated condition relative to the plain condition. However, the tissue boxes and small block figures, as different as the decorated versions were, had the same base shape as the objects in the plain condition. Also, the plain objects varied from each other in color, as the decorative versions did. Thus, one could argue that variation in color should have highlighted the constant spatial relation among the exemplars. Furthermore, it is natural that perceptually sparse exemplars have relatively small variation than rich exemplars, as has been the case in previous studies (e.g., Rattermann, Gentner, & DeLoache, 1990). Thus, the condition difference in infants' performance cannot be fully attributed to the difference in the variability of the exemplars.

Although the present results provide the first evidence for an effect of object features on infant spatial categorization, the results are in line with those findings with older children and adults showing that object perceptual richness does not necessarily interfere with learners' ability to attend to relational information. For instance, young children's counting is facilitated by brightly decorated pom-poms more so than visually plain, monochrome plastic disks (Petersen & McNeil, 2013). Moreover, adults' initial learning of an abstract scientific principle is better with rich displays (e.g., a simulation involving ants and food), relative to perceptually impoverished displays (e.g., a simulation involving dots and patches) (Goldstone & Sakamoto, 2003). As suggested by several researchers (e.g., Petersen & McNeil, 2013; Son, Smith, & Goldstone, 2011), perceptually complex objects possibly benefit relational learning in different ways than perceptually sparse objects do, including engaging learners' attention to the task better than perceptually simpler objects. In the present study, the more perceptually complex

boxes and blocks may have facilitated more attention to the spatial events than the perceptually plain objects. However, note that we failed to find any evidence of an engagement effect. Infants across the two conditions did not differ in the number of habituation trials viewed nor in their duration of looking times during the test phase.

Compared to the simple objects, the complex objects may also have offered an advantage because these objects provided more perceptual cues associated with a change in the support relation than the perceptually bland objects. For example, when a monochromatic block was placed in its referent box, the only perceptual change was in the degree to which the block remained visible. In contrast, when a decorated block was inserted into its referent box, several of its features became occluded. Thus, there were more perceptual changes with the perceptually rich than plain objects, changes that may have cued infants, especially the younger infants of 8 months, to the change in spatial relation, particularly because infants were tested with a containment relation after viewing a support relation during habituation. Perhaps, in learning settings where the object details highlight a critical feature of a relation (as in the partial occlusion of object parts in the present study), object details may make the relation more accessible, and relational learning might benefit more from complex objects than plain ones.

We presented two possibilities as to how decorated objects may have facilitated relational processing. However, given the many findings that perceptually sparse objects aid relational learning (particularly, generalization of relational structures) more effectively than perceptually rich objects (Kaminski & Sloutsky, 2010; Kaminski, Sloutsky, & Heckler, 2006, 2008; Rattermann, Gentner, & DeLoache, 1990; Son, Smith, & Goldstone, 2011; Uttal et al., 2013), why did infants in the current study, especially the

younger ones, fail to show an advantage of simplicity in transfer when habituated to perceptually simple objects? The discrepancy may be due to methodological differences. Infants in the current study were habituated to four exemplars of a relation prior to the test. In contrast, most of those studies documenting the benefit of simplicity in relational transfer presented their learners with a single set of objects (i.e., an instance of the relation) as the basis of generalization (e.g., Kaminski & Sloutsky, 2010; Kaminski, Sloutsky, & Heckler, 2008; Rattermann, Gentner, & DeLoache, 1990; Son, Smith, & Goldstone, 2008, 2011). Possibly, the advantage of a simple instance as a *ready-made* abstract representation is more pronounced when the learner must grasp the relational structure from a single instance compared to when the learner is given multiple exemplars of the relation (and sufficient time to compare them). Son, Smith, and Goldstone (2011) found an advantage of a simple sample over a rich sample in children's relational transfer when a *common* sample of a relation was presented across all trials, but not when the sample varied on every trial. Although their study did not manipulate the number of exemplars serving as the basis of generalization, their findings suggest that the strength of a simple sample in generalization may work best when the sample functions as a "model" of the richer instances. Infants in the current study were provided with multiple exemplars from which to compare and abstract a relation. Perhaps for this reason, the instances did not need to function as a model of a support relation. Consequently, the benefit of object simplicity may have declined in the present study than it might have had only a single exemplar been presented.

One contribution of the present results is in extending manipulations in the features of an object to infant learners. A second contribution is in documenting that

infants as young as 8 months can form an abstract categorical representation of support relations under ideal learning conditions. In previous work, the youngest infants who showed the ability to form an abstract categorical representation of support relations from multiple exemplars were infants of 10 months (Casasola & Park, 2013). Even in studies that presented a single exemplar, the results did not provide evidence that infants can easily generalize a support relation (Hespos & Spelke, 2004). The current finding suggests that infants of 8 months have the ability to form an abstract categorical representation of support relations from multiple exemplars, and that using objects with rich surface features can facilitate this ability. In addition, the manipulation of object features was most evident in our youngest infants, when the age groups of infants were analyzed separately. This result suggests that infants may be most sensitive to the impact of object features when first developing the skills to form a spatial category of support. By 14 months, infants no longer demonstrate as robust sensitivity to the object features, akin to manipulating the number of exemplars of a spatial relation presented (Casasola & Park, 2013). Thus, the present effect of object type may be most evident when infants and young children are first developing the skill to note and extend relations across exemplars.

In concluding, an important point to consider is whether the amount of complexity provided in the present study may have been especially well suited for the infants of 8 months. Although the objects in the decorated condition were more complex than the plain objects, these objects may nonetheless have been considered fairly simple to infants. It is an open question whether infants at either age will form the category of support when the objects have far more decorative features or whether there is an optimal

level of complexity, akin to the goldilocks effect (e.g., Kidd, Piantadosi, & Aslin, 2012). Future research should test between these possibilities.

In addition, the current finding that 8-month-old infants exhibited categorization of support relations might seem inconsistent with previous finding that even infants of 18 months can struggle to form the category of support with rich objects (e.g., Casasola & Cohen, 2002). However, the objects used in these former studies were toys (e.g., a stuffed monkey) or familiar objects (e.g., a cup and bowl). The use of these familiar objects, or perhaps the variety of objects used, plus the presentation of a variety of distinct support relations (e.g., encirclement and interlocking support relation) may have created a more difficult task. In contrast, the rich objects used in the present study were likely to be novel to the infant (e.g., a block decorated with a checkerboard pattern and two wings). Given the previous finding that perceptually rich features hinder when children are knowledgeable about the objects but not necessarily when their knowledge is limited (Petersen & McNeil, 2013), infants' successful categorization with rich objects in the present study may have been partly due to the unfamiliarity of the rich objects. In addition, infants in the present study may have been successful in forming the spatial category because, despite variations in surface features, all pairs of objects shared the same rectangular shape. Indeed, a study where infants were habituated to support relations depicted with perceptually rich objects sharing the same snowman-like shape showed that 10-month-old infants could form the category of support (Casasola & Park, 2013). Thus, the similarity in overall shape, perhaps combined with an appropriate level of complexity as well as the unfamiliarity of the rich objects, may have been especially effective in promoting infant spatial categorization.

To the degree that object surface features matter to infant spatial learning, the present findings have practical implications. We provide the first evidence that this variable matters in infant spatial categorization. Some degree of object complexity may play a triggering role in attending to the spatial relations, at least in some contexts and with infants of 8 months. It suggests that research should pursue the questions of when simplicity offers an advantage versus when complexity does so and whether the impact of object simplicity changes with development. It is our hope that the present study provides a steppingstone towards exploring these questions.

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