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Parts and Relations in Young Children's Shape-Based Object Recognition

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Abstract

The ability to recognize common objects from sparse information about geometric shape emerges during the same period in which children learn object names and object categories. Hummel and Biederman's (1992) theory of object recognition proposes that the geometric shapes of objects have two components—geometric volumes representing major object parts, and the spatial relations among those parts. In the present research, 18- to 30-month-old children's ability to use separate information about object part shapes and part relations to recognize both novel (Experiment 1) and common objects (Experiment 2) was examined. Children succeeded in matching novel objects on part shapes despite differences in part relations but did not match on part relations when there were differences in part shapes. Given known objects, children showed that they did represent the relational structure of those objects. The results support the proposal that children's representations of the geometric structures of objects are built over time and may require exposure to multiple instances of an object category. More broadly, the results suggest that the distinction between object part shape and part relations as two components of object shape similarity is psychologically real and developmentally significant.

The ability to recognize common objects from a few geometric components is well established in the mature visual object recognition system (Biederman, 1987; Hummel & Biederman, 1992). For example, given representations like those in Figure 1B composed of just two to four volumes in the proper relational structure, adults can recognize an instance of a familiar object category. Recent studies indicate that the ability to recognize well-known objects—a chair, a dog, a truck—from similarly sparse information about object shape first emerges between the ages of 18 and 24 months (Smith, 2009). Here, we examine the roles of the shapes of the object parts and of the relations among those parts in very young children's object recognition performance.

Smith (2003) conducted the first test of young children's ability to recognize common categories from minimal representations of their three-dimensional shapes. In that study, 18- to 24-month-old children's recognition of richly detailed, typical examples of common categories (Figure 1A) was compared with their recognition of sparse, geometric caricatures of the shapes of those same objects (Figure 1B). These "shape caricatures" were constructed from two to four three-dimensional volumes (e.g., cubes, spheres, cones) arranged to

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represent overall shape but without any fine-grained detail, color, or textural information. There were two measures of object recognition—a nonlinguistic play task, in which children were credited with knowing an object if they acted upon it in category-specific ways (e.g., pretending to brush hair with a hairbrush), and a forced-choice task, in which the children were asked to select a named object from a set of three. By both measures, children at the upper end of the age range recognized the sparse geometric representations as well as they did the richly detailed instances. Younger children did not: They recognized only the detailed examples, not the caricatures. These findings tell us that the ability to recognize sparse representations of object shape, as evident in adults, develops in late infancy, and furthermore, that it develops rapidly within a 6-month period. The result has been repeatedly replicated (Jones & Smith, 2005; Pereira & Smith, 2009; Son, Smith, & Goldstone, 2008) and has been linked to children's object name vocabulary size. In particular, object name vocabulary is a better predictor than age of children's recognition of objects from sparse geometric shape information. Consistent with this general finding, children with delayed object name vocabulary development show delays in the recognition of sparse representations of objects (Jones & Smith, 2005).

Hummel and Biederman (1992), in their account of adult object recognition, identified two components of shape similarity that might underlie recognition from sparse representations. These are the shapes of the parts themselves, which are represented as simple geometric volumes, and the relational structure of the whole. The central issue addressed by the present study is the role that each of these components might play in the development of very young children's ability to recognize sparse representations. A growing literature in perceptual development suggests a general shift from more part-like to more configural representations with age and with growing expertise in a perceptual domain (Pereira & Smith, 2009; Quinn, 2004; Rakison & Butterworth, 1998a, 1998b). A perhaps related trend in cognitive development also suggests a relational shift, with younger children attending to the components and older children attending to the structural relations in arrays of several objects (e.g., Kotovsky & Gentner, 1996). In these studies, attention to relational structure rather than components has also been related to expertise within a domain (Goswami, 1986, 1992) and to knowledge of the relevant lexical categories. These considerations suggest a possible part-shape to part-relations developmental trend in object recognition and also suggest that this trend may be related to children's experience with the individual categories and their names.

In Experiment 1, we used novel objects to separate Hummel and Biederman's (1992) two components of shape similarity and to ask whether 1.5- to 2-year-old children can match objects separately on the similarity in the shapes of their parts and on the similarity in the relations among their parts. In Experiment 2, we also examine these two separate components, asking whether 1.5- to 2-year-old children recognize common objects from the shapes of the parts or from the relational structure of the whole.

EXPERIMENT 1

All children in this experiment completed three tasks. The first tested the child's ability to match objects on one of two shape similarity components. Half of the children completed a Part Shape Matching Test and the other half completed a Part Relations Matching Test. The remaining two tasks were the same for all children. These tasks both measured children's ability to identify the same set of common objects. In one task, those objects were represented by "shape caricatures"—sparse three-dimensional geometric shapes that preserved the abstract shapes and spatial relations of the major parts. In the other task, the same objects were represented by realistic, richly detailed toy models. In addition to these three measures, we obtained a report of each child's productive vocabulary from the accompanying parent, who completed the MacArthur-Bates Communicative Development Inventory: Words and Sentences (CDI; Fenson et al., 1993), Part 1A: Words. This is a checklist of the first 680 words normatively acquired by children up to 30 months of age.

The Part Shapes and Part Relations Matching tasks were designed to challenge children's ability to make exact matches by using distracters that differed only in the key property being tested. Figure 2 shows examples of stimulus sets for testing children's matching of the part shapes (Figure 2A) and the part relations (Figure 2B) of an exemplar object. It should be easy for children to match the exemplar in Figure 2A to its exact copy, unless they represent the exemplar as one prominent part or as a collection of unrelated parts. In the latter cases, all three choices are equally good matches because all three have the same parts. Thus, the matching task in Figure 2A provides a strong test of children's representation of the relational structure of the exemplar. Analogously, the exemplar in Figure 2B should be easily matched to its exact match unless children represent the exemplar only in terms of its global structure (a smaller part on some larger part) without representation of the individual part shapes. Thus, the matching task in Figure 2B provides a strong test of children's representation of the individual part shapes.

The shape caricature recognition task (similar to that used in Smith, 2009) was included to examine the relation between children's attention to the two different aspects of shape similarity and their ability to recognize common objects from sparse representations that include both abstract part shape and part relations information. The realistic toy recognition task was included to determine that children were in fact familiar with the common categories tested.

Participants

Forty-eight children (24 males) aged between 16 and 28 months were recruited by letter and follow-up telephone calls to families with children in this age range identified from public birth records. The children were randomly assigned to one of two groups—the Part Shapes Test group (mean age = 21.5 months, SD = 2.7 months, range = 17 to 28 months) and the Part Relations Test group (mean age = 20.8 months, SD = 2.3 months, range = 16 to 26 months). Children in the two groups were matched for total vocabulary (M = 124.4, SD = 104, range = 12 to 373 words) and for object name vocabulary (M = 58, SD = 45.2, range = 3 to 155 words). The racial and economic composition of the sample reflected those of the local population, with the majority of infants coming from European American, middle- and lower middle-class families. Children received a small toy or T-shirt as thanks for their participation.

Stimuli

1. Part Shapes and Part Relations Tests—Twelve sets of novel objects were constructed from clay. Each set consisted of a category exemplar and three test objects, all painted the same color. The exemplar was composed of two to four parts and labeled with a novel name. Each set of three test objects contained one that was identical to the exemplar and two distracters. For the 6 sets used in the Part Shapes Test, the choices were an identical match and two distracters that differed from the exemplar in part shapes but matched the exemplar in the spatial arrangement of their parts (Figure 2A). To succeed in this task, children had to attend to the shapes of the parts to discriminate the correct match from the two distracters. In the other 6 sets, used in the Part Relations Test, the distracters differed from the exemplar in the relations among the parts, but the parts of all items were the same shapes (Figure 2B). To succeed in this task, children had to attend to the relations among the parts to discriminate the correct match from the two distracters.

2. Shape Caricature Recognition Task—Ten object names known by at least 50% of 30-month-olds were chosen from the CDI (Fenson et al., 1993). Those object names were *basket, camera, ice cream, telephone, nail, butterfly, couch, lollipop, kitten*, and *truck*. "Shape caricatures" of these objects, like those in Figure 1B, were constructed from two or three parts carved from grey-painted Styrofoam and assembled in the same spatial arrangement as the parts of the real object they represented. We refer to these as "sparse" category representations, or "sparse" objects.

3. Realistic Object Recognition Task—Small, realistic toy representations of the same categories tested in the shape caricature recognition task were purchased (see examples in Figure 1A). The minimum dimension for any toy (i.e., height or width or depth) was 4.5 cm and the maximum was 10 cm. We refer to these as "rich" category representations, or "rich" objects.

Procedures

Children were welcomed to the laboratory in a reception area, where they had a warm-up period of toy play with an experimenter while the study was explained to the accompanying parent and consent was obtained. The child was then invited to play some special games with the experimenter. Experimenter, child, and parent moved to a testing room, where the child was seated on the parent's lap facing the experimenter across a table.

1. Part Shapes and Part Relations Tests—Testing of every child began with the Part Shape or Part Relations Matching Test. The procedures in the two tests were the same. Participants were shown an exemplar object, were told its name (e.g., "Look, this is a dax"), and then were given time to play with and examine it. After 15 seconds, the experimenter reclaimed the exemplar and placed three test objects on the table in random order, about 25 cm apart in a line in front of the subject. The infant was then asked for another member of the named category (e.g., "See my dax? Can you give me another dax?"). The first object grasped, shown, or handed over by the infant was recorded. If two objects were simultaneously chosen, the experimenter repeated the request until one object was grasped, shown, or handed over.

2. Shape Caricature Recognition Task—The second task for all children, administered directly after the first, was the shape caricature recognition task. Three shape caricatures (sparse objects) were presented on each of 10 trials. The shape caricatures were arranged in a horizontal line within reach of the participant, and the child was asked for one object by name (e.g., "See all of these? Can you get me the ice cream?"). Trials and objects within trials were ordered differently for different infants. Each of the 10 object categories was tested once.

3. Realistic Object Recognition Task—The realistic object recognition task always followed the shape caricature recognition task because the object categories tested in the two tasks were the same, and the realistic toys would have primed these categories for the shape caricature test. On each of 10 trials, participants were shown three of the realistic toys (rich objects) and were asked to point to the one object named by the experimenter. Trials and objects within trials were ordered differently for different infants. Each object category was tested once. Following completion of all three tests, the experimenter, child, and parent returned to the reception area where the parent completed the CDI word checklist.

Results

Children in both groups showed near-perfect familiarity with the categories represented in the shape caricature recognition task by correctly identifying high proportions of the rich typical instances in the realistic object recognition task (Part Shapes Test group, $M = 0.90$, $SD = 0.14$; Part Relations Test group, $M = 0.89$, $SD = 0.12$). The two groups of children also recognized similar proportions of sparse objects in the shape caricature task (Part Shapes Test group, $M = 0.64$, $SD = 0.18$; Part Relations Test group, $M = 0.58$, $SD = 0.19$). A 2 (Part Shapes Test group/Part Relations Test group) × 2 (Object Type: sparse/rich) mixed analysis of variance confirmed that the proportions of rich objects recognized was reliably greater than the proportions of sparse objects recognized, $F(1,46) = 109.7$, $p < .001$), which replicates prior findings in children this age (e.g., Pereira & Smith, 2009; Smith, 2003). However, children in both groups recognized the sparse objects at levels better than chance, both $t(23) > 6.6$, $p < .001$. Sparse object recognition was also correlated with the number of object names in children's vocabularies, $r(50) = .37$, $p < .01$), again replicating previous results (Pereira & Smith, 2009).

The key new question for this experiment is the nature of the object shape representations that support children's recognition of the sparse caricatures. The Part Shapes Test assessed children's representation of the shapes of the parts, and the Part Relations Test assessed their representation of the spatial relations among the parts. A comparison of performance in these two conditions suggests that children were attending to the part shapes but perhaps not to the part relations of these novel objects. Children in the Part Shapes Test group made a significantly higher proportion of correct matches ($M = 0.49$, $SD = 0.24$) than children in the Part Relations Test group ($M = 0.36$, $SD = 0.17$), $t(46) = 2.08$; $p < .05$, and only the mean score of children completing the Part Shapes Test was significantly greater than chance, $t(23) = 3.18$; $p < .005$.

Children's chance-level performance in the Part Relations Test is particularly notable because the correct match was an object identical to the exemplar. All that these children had to do to succeed was to perceive the exemplar's relational structure and notice its difference from the relational structures of the distracters. The changes in relational structures of the distracters also changed the overall shapes of these objects relative to the exemplar, yet children this age were still unable to make the correct match. These results suggest that children's development of caricature representations for common categories might begin with representations of the parts and proceed to representations of the relations —an idea that has some precedence in the developmental literature (e.g., Gentner, 1983; Rakison & Butterworth, 1998a, 1998b) and which we consider in the General Discussion.

To examine the relationship between children's abilities to recognize the shape caricatures of familiar objects and their representations of part shapes and part relations, we classified each child's performance in the shape caricature recognition task and in either the Part Shapes or Part Relations Test as passing or failing, and then examined the relationship between the two kinds of tasks. Passing in each task was defined as performance greater than 50% correct. This threshold was chosen to be clearly above chance-level performance of .33, and the probability of any child passing by chance alone was less than .10. Table 1A shows the proportion of children in the Part Shapes Test group who produced each combination of passing and/or failing each of the two tasks. As is apparent in the table, twice as many children passed the caricature task as passed the Part Shapes Test, with one third passing both. The key result, however, is that no child passed the Part Shapes Test if they did not also pass the Sparse Object Recognition Test. Table 1B shows the proportion of children in the Part Relations Test group who produced each combination of passing and/or failing in the two tasks. Many more children passed the caricature task than passed the Part Relations Test, and indeed only three children passed both. But again, the key finding is that no child passed the part relations test if they had not also passed the sparse caricature recognition task.

The developmental priority of recognition of caricatures of known categories across matching novel objects on either part shapes or part relations suggests that learning about common object categories may play a role in fostering these representational skills. This idea is supported by reliable correlations between the number of nouns in children's individual productive vocabularies and their performance in both the Part Shape Test, $r(24) = .41$, $p < .05$, and the Part Relations Test, $r(24) = .54$, $p < .005$. Accordingly, in Experiment 2, we asked whether one component of the shapes of sparse representations of common categories—part shapes or part relations—is more important than the other to children's recognition of those categories.

EXPERIMENT 2

In this experiment, we measured children's recognition of shape caricatures of common objects in a forced-choice task, when the caricatures varied either in the shape of one part or in the spatial relation of one part to the whole. Figure 3 provides examples of the two kinds of test sets. The Part Shape Test differs from that used in Experiment 1 in that only one part varies across the distracters. This was done to make the task harder and to diagnose whether children were representing all of the individual parts: In Experiment 1, children might have succeeded not because they attended to all of the parts but because they noticed that one was different. The question here was whether, in their representation of a known object, the individual part shapes were important to decisions about category membership. Thus, Figure 3A shows three possible representations of an ice cream cone that differ only in the shape of one part, with one choice having the appropriate part shape for the category and also, as in Experiment 1, being an exact match. If children attend to the shapes of the parts and all of the individual parts matter when recognizing common categories from such sparse representations, then this should be an easy discrimination task. The Part Relations Test is also a purposely harder relational task. As in Experiment 1, all of the distracters share the same part shapes, but in this experiment, attention to relational structure is tested by varying the relation of just one part to the whole to form the distracters. Thus, Figure 3B shows three other possible representations of an ice cream cone. If children attend to the relational structure of the object in such sparse representations, then they should be able to pick the appropriate representation, the exact match which shares both the part shapes and the relations among parts. Unlike in Experiment 1, in this task, there was no exemplar object. Instead, as in the shape caricature task of Experiment 1, children were presented with three caricatures and were asked by name to find the category instance. Thus, in this experiment, children compared the stimulus representations to their internal representations of the category.

Method

Participants—Thirty-two infants (16 males), aged from 19 to 24 months, participated. Participants were recruited as in Experiment 1, and these methods again resulted in a sample that reflected the racial and economic composition of the local population, predominantly European American middle- and lower middle-class families. Children were randomly assigned to one of two groups: the Part Shapes Caricature Test group (mean age = 21.4 months, $SD = 1.3$ months, range = 20 to 24 months) or the Part Relations Caricature Test group (mean age = 21.3 months, $SD = 1.14$, range = 19 to 24 months). As in Experiment 1, parents reported their children's productive vocabularies using the CDI (Fenson et al., 1993). As is typical for this age group, there was considerable variability in both total vocabulary size ($M = 245.7$ words, $SD = 160.3$, range = 28 to 554 words) and object name vocabulary ($M = 103.9$ words, $SD = 65.9$, range = 10 to 247). All children in this experiment received a small toy or T-shirt as thanks for their participation.

Stimuli

1. Part shapes and part relations tests: The stimuli for each task were caricature objects representing the same 10 common object categories used in the shape caricature recognition task in Experiment 1. All stimuli were constructed from two to four three-dimensional parts carved from Styrofoam and painted grey. Each part of the caricature was a geometric volume (e.g., a circle, sphere, cube, cone, etc.) chosen to resemble a major part of the object.

Stimuli for the Part Shapes Test were sets of three caricatures of each of the 10 object categories. In each set, there was one caricature—identical to the caricature used in the shape caricature recognition task in Experiment 1. This correct-choice object preserved both the part shapes and the relational structure of the object that it represented. The two other choices were distracters that differed from the first, from each other, and from the represented category only in the shape of one of the parts (Figure 3A). In each set of test stimuli for the Part Relations Test, the correct-choice caricature again preserved both the part shapes and the relational structure of the object that it represented, and two distracter caricatures differed from the first, from each other, and from the represented category only in the way in which one of the parts was spatially related to the whole (Figure 3B).

2. Realistic toy recognition task: The stimuli for this task were the same 10 detailed, realistic toys that were used in Experiment 1.

Procedure—The procedure for both the Part Shapes and Part Relations Tests was the same as for the shape caricature recognition task in Experiment 1—that is, the three choice objects were laid out on the table and the experimenter asked the child to select the object by name (e.g., “Where is the ice cream? Show me the ice cream”).

The realistic toy recognition task always followed the Part Shapes or Part Relations Test, and the procedure was the same as in Experiment 1.

Results

As in Experiment 1, children in both groups showed their familiarity with the 10 test categories by correctly identifying high proportions of the rich typical instances in the realistic object recognition task (Part Shapes Test group, $M = 0.89$, $SD = 0.11$; Part Relations Test group $M = 0.90$, $SD = 0.10$). The key question for Experiment 2 is what information children represent about the parts and the relational structure of such common objects, and specifically whether children can discriminate among sparse representations of common categories that differ only in the shape of a part or only in the relations among the parts. The results suggest that children’s judgments of category membership depend very much on the relational structures of the candidate objects but may depend less on the specific shape of an individual object part. Children identified the correct caricature significantly more often in the Part Relations Test (proportion correct, $M = 0.49$, $SD = 0.12$) than in the Part Shapes Test (proportion correct, $M = 0.39$, $SD = 0.16$), $t(30) = 2.15$; $p < .05$. That is, children were able to discriminate the complete caricature from the distracters that differed only in their relational structure better than they were able to discriminate that same caricature from distracters that differed only in the shape of one part. The mean number of correct choices in the Part Relations Test was also significantly greater than chance (0.33), $t(30) = 5.54$, $p < .001$, whereas the mean number of correct choices in the Part Shapes Test was not, $t(30) = 1.45$, *ns*.

As in Experiment 1, children’s scores in the Part Shape Test were positively related to the reported number of object names in their productive vocabularies, $r(14) = .46$, one-tailed $p < .04$). However, object name vocabulary size was not at all predictive of children’s scores in the Part Relations Test, $r(14) = .16$, *ns*. Thus, the relation between object name vocabulary size and attention to overall object shape that has been repeatedly demonstrated in previous studies (see, e.g., Smith et al., 2002) is not shown here. This may be due to the more narrow range of performances in the Part Relations Test and the small *n*, or it may reflect a more complicated aspect of the relation between learning category names and the representation of object shape. Parent report of children's productive knowledge does not indicate the range of category instances for which children know the object name. It may be that this is most critical for children's representation of relational structure.

The pattern of results for recognizing caricatures of well-known categories is different from the pattern for the recognition of novel objects in Experiment 1. For well-known objects, but not for the novel objects in Experiment 1, these children were highly sensitive to the relational structure. Children performed less well in this task on the Part Shapes Test, but this test was harder than in Experiment 1, in that it required children to discriminate among the choices on the basis of a specific single part rather than on any or all of the parts. The task in Experiment 2 is also importantly different from that in Experiment 1 in that children were presumably comparing the presented choices to representations of the objects in memory, representations that were presumably built up across many different instances in the world. In Experiment 1, correct choices required the child to extract and compare the shapes and relations among single instances experienced for the very first time. These facts fit with the idea that as children are learning common categories, they are learning and representing the relational structures of the category members.

GENERAL DISCUSSION

Object shape is important to children's early object category and noun learning (e.g., Gershkoff-Stowe & Smith, 2004; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002), yet we know very little about the aspects of shape that matter to young children. Theories of the mature human object recognition system offer relevant hypotheses. Object-centered theories such as that proposed by Hummel and Biederman (1992) posit internal representations of objects that are sparse and that are composed of two separable components—the major parts and the relational organization of those parts. Very young children's ability to recognize common categories given sparse representations suggests that object-centered theories of mature object recognition are capturing aspects of the developing system. Moreover, the results from Experiments 1 and 2 provide new information that these two components of shape similarity are also separable in development, a result predicted by a recent computational model of the development of object recognition (Doumas & Hummel, 2010). Whereas the individual part shapes may dominate when young children first compare novel objects, the relations among the parts are represented and matter to their recognition of known categories from sparse shape representations.

Object-centered theories are just one class of theory of mature human object recognition (Peissig & Tarr, 2007). Other view-based theories offer accounts in which the surface details of objects matter greatly to recognition. For example, Ullman's Fragment Theory (Ullman, 2007) proposes that people store experienced fragments of perceived objects in category-specific detail—the whiskers, paws, and heads of cats and the wheels, doors, and lights of cars. In the literature on adult and machine object recognition, there is growing agreement that both object-centered and view-centered accounts are needed to explain the full range of mature object recognition (e.g., Graf, 2006; Peissig & Tarr, 2007; Xu & Kuipers, 2009). Fragment-like representations explain how we can recognize the dog from just a nose sticking out from a blanket. Object centered and sparse shape representations like those examined here explain adult knowledge about part structure and may also be particularly relevant to category generalization (Biederman, 1987; Son et al., 2008). Thus, infants and children may be building multiple kinds of object representations. Indeed, evidence from younger infants (Quinn, 2004) and also toddlers (Pereira & Smith, 2009; Rakison & Butterworth, 1998a, 1998b) suggests that young children do represent and recognize common objects from detailed fragments that are highly predictive of category membership. Because some machine vision theories construct sparse representations by integrating across fragments (Xu & Kuipers, 2009), a relevant question for future research is whether and how children's fragment-based representations of common categories may relate to their emerging representations of both the major parts and the relational structure among those parts.

The present results are perhaps best understood under this view that object shape is not a unitary psychological construct. Children's attention to the part shapes when they first encounter an object suggests that there may be some representational priority for parts (see Mash, 2006; Poirel, Mellet, Houdé, & Pineau, 2008; Vurpillot, 1968). Although it seems likely that children also represent and store information about the parts of well-known objects, the present results show that they are also building relational representations of the relations among those parts. These relational representations in turn may lessen the importance or specificity of individual part shapes. Attention to relational structure may enable broader category generalization and a developmental shift to a deeper and more essential representation of shape than the shapes of the specific parts themselves.

In turn, children's representations of the relational structure of whole objects may depend on a particular kind of experience with instances. In particular, children may need experience with multiple instances of a category to abstract their common sparse structure (Doumas & Hummel, 2010; Gentner & Namy, 1999). Mash (2006) also tested the two components of Hummel and Biederman's (1992) account, examining elementary school-aged children's ability to match drawings of novel objects on the shapes of the parts or relational structure, and found that even children up to 8 years of age had difficulty matching these novel objects by relational structure. Mash's results, in the context of the present finding that much younger children represent the relational structure of known categories, testifies to the potentially powerful importance of category learning in building these relational representations. A key next step is to determine the kinds and amounts of experience that underlie these sparse shape representations of common categories. This is particularly important given the findings that children who are at risk for language delay also show delays in recognizing objects from sparse representations of their shapes (Jones & Smith, 2005) and also lack a shape bias in object name learning (Jones, 2003; Tek, Jaffery, Fein, & Naigles, 2008).

The developmental trend suggested in this discussion evokes Gentner's Structure Mapping Engine model of analogy (Gentner, 1983). That theory has been applied to children's growing ability to match sets of objects on the basis of the individual object similarities versus the relational structures within the sets (e.g., Kotovsky & Gentner, 1996). The evidence in that literature suggests a developmental shift from more object matches to more relational matches late in the preschool period and provides a number of important insights about the kind of experiences and task structures that facilitate relational matching, including the progressive alignment of many different instances of the relation (e.g., Gentner & Namy, 1999), having a label for the relation (Gentner, 2003), and direct comparison (e.g., Graham, Namy, Gentner, & Meagher, 2010; Kotovsky & Gentner, 1996; Son, Smith, & Goldstone, 2011). In brief, there appears to be a common developmental direction in children's emerging sensitivity to the relational structure among objects and among the parts within a single object. This similarity points to interesting directions for future research. However, in our view, this similarity in the two developmental trends does not imply that the relational shift generally characterized as occurring between 4 and 6 years of age actually occurs much earlier. The processes examined in this article are processes of visual object recognition and seem likely to involve fundamentally different neural mechanisms than relational judgments in the context of analogy and the comparison of sets of objects (Peissig & Tarr, 2007; Reisenhuber & Poggio, 2000). Humans are visual animals, and visual object recognition impacts almost all aspects of human cognition. In view of this importance, it is surprising how little we know about the development of visual object recognition during the period in which children learn categories and object names. The present study suggests that these processes may be changing in fundamental ways during this developmental period.

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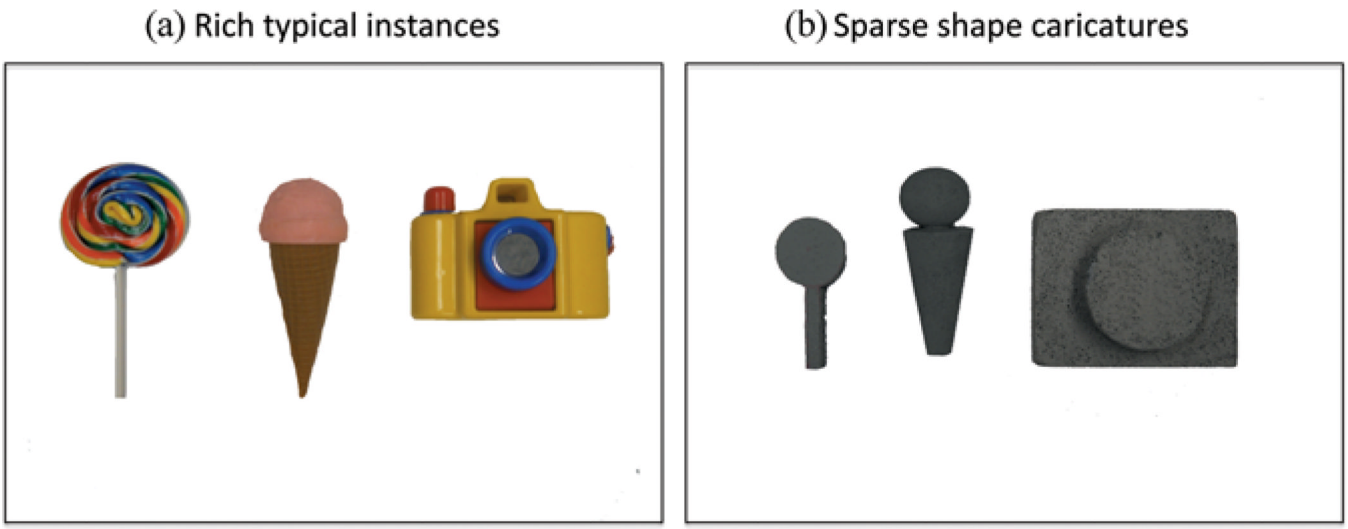

FIGURE 1.

A) Realistic toy representations of three common object categories. B) Shape caricature representations of the same three object categories, with major parts represented by simple volumes in grey Styrofoam, with relational structure of the represented object preserved. (Color figure available online.)

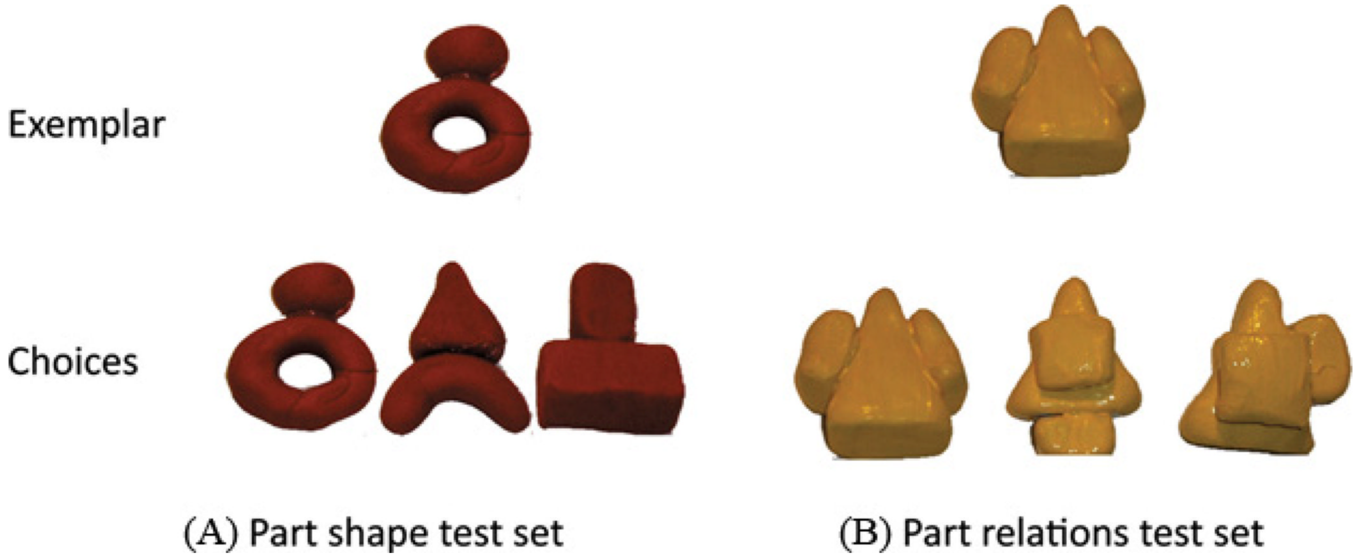

FIGURE 2.

Experiment 1. Example sets of novel objects used in the Part Shapes and Part Relations Tests of 1.5- to 2-year-old children. A) Part Shapes Test set: an exemplar object, an identical test object, and two distracters differing from the exemplar in part shapes, matching in relations among parts. B) Part Relations Test set: an exemplar object, an identical test object, and two distracters matching the exemplar in part shapes, differing in relations among the parts. (Color figure available online.)

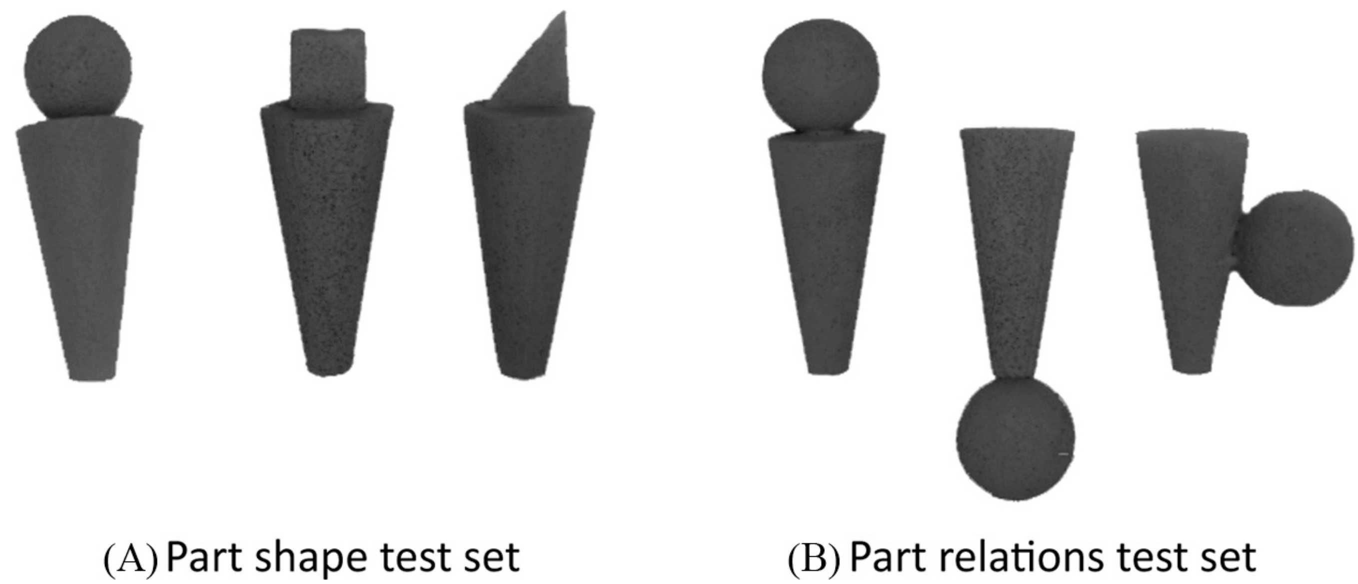

FIGURE 3.

Experiment 2. Example sets of shape caricature representations of common objects. A) Part Shapes Test set: three representations of an ice cream cone that differ only in the shape of one part. B) Part Relations Test set: three representations of an ice cream cone that differ only in the spatial arrangement of the parts.

TABLE 1

Experiment 1. Proportions of Children who Produced Each Combination of Passing and/or Failing the Shape Caricature Recognition Task and A) the Part Shapes Test or B) the Part Relations Test

		Shape caricature recognition					
		Pass	**Fail**			**Pass**	**Fail**
A. Part	Pass	.33	0	B. Part	Pass	.125	0
Shapes Test	Fail	.33	.33	Relations Test	Fail	.50	.375

Note. "Pass" is defined as a score of more than 50% correct. $N = 24$ in each group.