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Infants' Attention to Object Structure in Early Categorization

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Three experiments with object-manipulation tasks examined the effect of object structure on 14-, 18-, and 22-month-olds' categorization. In Experiment 1, categorization of animals and vehicles was tested when object structure was normal and when it was violated by moving parts (legs or wheels) into a novel configuration. In Experiment 2, categorization of animals, vehicles, and furniture was examined when object structure was modified in orientation (e.g., legs inverted) or in configuration (e.g., legs at tangential angles). In Experiment 3, infants' attention to texture in categorization was tested. The results of the studies showed that 14- to 22-month-olds attend to object parts and structural configuration to categorize and that they do not attend to object texture. There is a perceptual basis for early categorization at the superordinate-like level, and infants are constrained in the parts and object structures they recognize in this process.

A focus of recent developmental research on categorization has been infants' ability to form what Rosch (1978) labeled basic-, superordinate-, and subordinate-level classes (e.g., Behl-Chadha, 1996; Eimas & Quinn, 1994; Mandler, Bauer, & McDonough, 1991). According to Rosch and her colleagues, these *taxonomies* fall into a hierarchy whereby some classes of objects are easier to distinguish than others (Mervis & Rosch, 1981; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). They claimed, for example, that infants form basic-level categories (e.g., dogs, cats, cars, boats) earlier than they do superordinate-level categories (e.g., animals, vehicles, tools, plants). It has been argued that this developmental sequence results from the high level of within-category similarity of basic-level categories in comparison to the low within-category similarity of superordinate categories.

An alternative view of the development of categorization has since been proposed by Mandler and her colleagues, who claimed that a version of superordinate categories, which they called *global,* develop prior to those at the basic level (e.g., Mandler, 1992, 1993; Mandler et al., 1991; Mandler & McDonough, 1993). This claim was based on evidence that 18-month-old infants differentiated the superordinate domains of animals and vehicles but did not differentiate basic-level contrasts within these domains such as dogs and rabbits, and cars and boats. Although by 24 months infants distinguished these basic-level contrasts, they still failed to form categories with several other basic-level contrasts such as dogs and horses, and cars and trucks.

Although there is disagreement over the developmental primacy of the basic and the superordinate level, there is a prevailing theory for the abilities required by infants to form superordinate or global categories. The putative view, based in part on the low within-category similarity of the superordinate level, is that infants cannot rely on perceptual similarity and that conceptual understanding must direct behavior (e.g., Mandler, 1992, 1993; Murphy & Medin, 1985). Mandler et al. (1991) illustrated this point in their discussion of infants' categorization of toys drawn from superordinate domains:

> It cannot be perceptual similarity that is mediating touching behavior because of the great diversity of the objects we have used. . . . We assume that conceptual understanding of some sort must be guiding the behavior, since there is no evidence that categorically related, perceptually diverse objects automatically elicit sequential touching behavior. (p. 293)

According to Mandler and her colleagues, the conceptual understanding required to form superordinate categories—redefined as global because of the absence of basic-level classes nested within them—is knowledge about one or two crucial abstract characteristics called *image schemas* or *conceptual primitives.* Mandler (1992) proposed that a conceptual format is constructed through a process of perceptual analysis whereby the infant recodes aspects of the perceptual display into a simpler, accessible form. Thus, one global category that differentiates animals from nonanimals might be based on an image schema of self-initiated biological motion, and another that dif-

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ferentiates what can act as a container and what cannot may be based on image schemas of envelopment and support. It is through this process that infants acquire knowledge about the kinds of things objects are (Mandler & McDonough, 1993).

Despite the prevalence of this view, a number of recent studies have suggested that perceptual similarity along certain dimensions or attributes may be sufficient for infants to form superordinate-like categories. Behl-Chadha, Eimas, and Quinn (1995) used the paired-preference paradigm to explore whether young infants can form representations for superordinate-like categories. The studies showed that 3- and 4-month-old infants will form a representation for mammals that includes giraffes, cats, dogs, deer, and horses but excludes birds, fish, and furniture. In a later study, Behl-Chadha (1996) found that 3- and 4-month-olds formed multiple representations of furniture: Not only did the infants form categorical representations of chairs and couches that excluded beds, but they also formed categorical representations of beds, chairs, couches, cabinets, and tables that excluded mammals. Similarly, in a study with older infants Ross (1980) found that 12-, 18-, and 24-month-olds formed categorical representations of superordinate-like categories such as furniture and food in which members varied considerably in appearance.

Perhaps more compelling evidence against the notion that early categorization relies on conceptual knowledge came from a series of studies by Rakison and Butterworth (1998) that used the object-manipulation paradigm with 14–22-month-olds. In one experiment, infants categorized objects from superordinate domains with different parts (i.e., legs and wheels) approximately 8 months before they categorized objects from superordinate domains with the same parts (i.e., legs). In a second experiment by the same authors, it was shown that infants between 14 and 18 months of age classified on the basis of parts (objects with legs and objects with wheels) instead of category relations (animals and vehicles) when presented with a choice to sort on either basis. By 22 months, however, a single part was no longer sufficient as the basis for categorization. Thus, as posited by Tversky (1989; Tversky & Hemenway, 1984), children may organize knowledge *partonomically,* by subdividing objects into parts, as well as taxonomically, by subdividing objects into kinds.

One issue that remains unclear is whether infants in the second year attend to the perceptual similarity of parts of objects or whether they attend to certain properties suggested by those parts. It is possible that the perceptual similarity of parts alone does not mediate categorization because the same parts often differ in appearance; for example, animal legs may vary in appearance from exemplar to exemplar (Rakison, 1996). An alternative to the perceptual similarity explanation is that infants in the second year attend to structural aspects of an object—that is, its configurational organization—and parts, such as legs and wheels, are important to this structure. This theory is supported by Tversky (1989), who found that not only do 5-year-old children make taxonomic groupings more readily when exemplars share parts, but they also detect missing parts faster when they are external and affect structure and shape (e.g., wheels) than when they do not affect structure or shape (e.g., headlights). Tversky subsequently used the term *canonical contour* to refer to the structural configuration of an object; for example, the tail of a fish is more canonical than the gills in that it has a greater influence on structure and shape.

The role of parts and structure was also examined by Palmer, Rosch, and Chase (1981), who found that adults agree that certain viewpoints of common objects are more informative, or canonical, than others. Moreover, the canonical viewpoints were found to be those that showed the more important parts in contour. Thus, large parts such as legs and wheels may be important to infants during categorization because they are a salient aspect of objects' contour. Finally, Van de Walle and Hoerger (1996) tested whether early categorization might be based on overall part structure. They familiarized 9-month-old infants with animal-like or vehicle-like objects that differed in the extent to which they had curved contours and smoothly joined parts. (The stimuli were otherwise matched for size, overall shape, texture, and color.) When presented with a novel member of the familiar group and a member of the unfamiliar group, infants showed a preference for the latter. The authors concluded that infants can distinguish objects solely on the basis of overall part structure; that is, curvilinearity versus rectilinearity.

Another explanation for the importance of parts and structure in categorization is that they may suggest causal relations. Tversky and Hemenway (1984) argued that children attend to relations among parts and structure because "it seems to form the basis of intuitive causal reasoning and naive induction" (p. 190). They claimed that this intuitive causal reasoning develops from the notion that different parts suggest distinct functions whereas similar parts have comparable functions. A similar conclusion was drawn by Madole and Cohen (1995), who examined 14- and 18-month-olds' attention to different kinds of form–function correlations. Infants in both age groups were found to be sensitive to form–function correlations within the parts of an object (i.e., when the form of a part predicts its function), but only the 14-month-old infants attended to form–function correlations that were inconsistent with those found in the real world (i.e., when the form of one part was correlated with the function of an altogether different part). The authors concluded that over time infants pick up on form–function correlations that suggest causal mechanisms, a view that is consistent with that of Murphy and Medin (1985), who argued that adults do not attend to correlational information per se but rely on correlations as a basis for primitive theories.

The three experiments presented here were designed to assess whether infants form superordinate-like categories by attending (a) to parts independently, (b) to the structure of parts, (c) to functional aspects of parts, or (d) to textural differences among stimuli. Experiment 1 examined whether infants attend to parts independently to form categories. Infants at 14, 18, and 22 months of age were presented with a control task with unmodified animals and vehicles and with three tasks in which the structure of animals and vehicles was systematically violated by moving parts into a novel configuration. It was hypothesized that infants would categorize stimuli with a novel structural configuration if they attend to parts independently. In Experiment 2, responses to two distinct violations of structural properties in same- and different-parts contrasts were measured. The first type of violation preserved the structure of parts but not the structural relationship between parts and the rest of the object; for example, the four legs of a cow were moved, as a unit, into a novel orientation. The second type of violation affected the structural relationship of parts as well as that between parts and the rest of the object; for example, each of the four legs of a cow was moved into a novel orientation tangential to the other three legs.

In Experiment 3, infants' attention to texture as the basis for categorization was tested. The rationale for this experiment was to eliminate texture as an explanation for the infants' categorizing behavior in Experiments 1 and 2, and in previous studies (e.g., Mandler et al., 1991; Rakison & Butterworth, 1998). For example, Rakison and Butterworth found that 14- and 18-month-old infants categorized toy animals from toy vehicles and toy furniture from toy vehicles more readily than they did toy animals from toy furniture. However, in each of these cases there was a textural confound; that is, infants categorized on contrasts of metal stimuli (vehicles) versus plastic stimuli (animals and furniture) but not on contrasts of all plastic stimuli (animals and furniture). There were two tasks in Experiment 3 to test whether textural properties direct infants' categorization. In the first task, infants were presented with animals and vehicles that were fashioned from the same material, and in the second task, infants were presented with stimuli that could be categorized either by parts (i.e., legs vs. wheels) or by texture (i.e., plastic vs. metal). The object-manipulation technique was used in all three experiments.

Experiment 1

Method

Participants. Forty-eight infants participated in the experiment: 16 at 14 months (mean age = 14 months 11 days; age range = 13 months 14 days to 14 months 21 days), 16 at 18 months (mean age = 18 months 7 days; age range = 17 months 18 days to 18 months 17 days), and 16 at 22 months (mean age = 21 months 28 days; age range = 21 months 18 days to 22 months 19 days). There were equal numbers of boys and girls in the 14- and 22-month-old groups. In the 18-month-old group, there were 9 girls and 7 boys. Six additional infants were tested but were not included in the study: 3 infants because of fussiness or crying, 2 infants for not engaging in the tasks, and 1 infant because of experimenter error. Thirty-six infants were recruited from an existing pool of volunteer parents who had responded to an advertisement for a previous unrelated experiment. Twelve infants (4 in each age group) were recruited from the University of Sussex crèche facility. Parents on the volunteer list were contacted initially by letter and later by telephone.

Stimuli. The stimuli were 3-D realistic scale models of animals and vehicles that ranged in size between 4 and 6 cm in length and 2 and 4 cm in height. The animal stimuli were a cow, a dog, a goose, and a walrus, and the vehicle stimuli were an all-terrain vehicle (ATV), a train, a bus, and a motorbike. Each animal exemplar possessed legs, and each vehicle possessed wheels, though the legs or wheels of the exemplars within each category varied in form and number (e.g., a goose had two legs and a walrus had four flippers). The animals were made from rubber or plastic and had no moving parts. The vehicles were made from metal and had no moving parts. The animals and vehicles were chosen because they allowed for a contrast of stimuli with different parts and because they made the study comparable with previous experiments (i.e., Mandler et al., 1991; Rakison & Butterworth, 1998).

The experiment was composed of one task that was a control contrast between unmodified animal and vehicle exemplars and three contrasts where the part structure of objects was systematically modified. A description of each task is given in Table 1. In the control task, infants were presented with the four animals (a cow, a dog, a goose, a walrus) and the four vehicles (a bus, an ATV, a train, a motorbike). For the remaining three tasks, novel versions of the stimuli were generated by detaching, moving, and re-attaching parts (legs and wheels). Parts were segmented into individual units (e.g., four separate legs), and then each part was situated in a position tangential to the host object and to the other parts; for example, the cow had one leg pointing sideways on each side of its stomach, one pointing upward, and one pointing downward. Thus, legs could not offer "support" nor could wheels "roll." In a second task, the animals and vehicles were confounded by moving their parts in the way described above. Thus, the task consisted of four animals (a cow, a dog, a goose, a walrus) with a leg on four sides of each exemplar and four vehicles (a bus, an ATV, a train, a motorbike) with a wheel on four sides of each exemplar. In a third task, animals and vehicles were again confounded in the way described above except that each object possessed the part of the other category. Thus, each of the four animals (a cow, a dog, a goose, a walrus) had a wheel on four sides, and each of the four vehicles (a bus, an ATV, a train, a motorbike) had a leg on four sides. In a fourth task, animal and vehicle exemplars were again confounded; however, two objects from each category were attached to legs and two were attached to wheels. The task consisted of two animals with a leg on four sides (cow and dog) and two animals with a wheel on four sides (goose and walrus), and two vehicles with a leg on four sides (bus and motorbike) and two vehicles with a wheel on four sides (ATV and train). The fourth task was closer to a true confound because infants could group together objects drawn from the same taxonomic category—albeit by treating equivalently normal category members and the bodies of modified category members—or they could group together objects with the same parts (i.e., objects with wheels and objects with legs).

To make it easier to refer to the four tasks, we called Task 1 the *control task,* Task 2 the *within-category confound,* Task 3 the *between-categories confound,* and Task 4 the *across-categories confound.* Each infant participated in all four object-manipulation tasks. Thus each infant completed the control task, within-category confound, between-categories confound, and across-categories confound. A Latin square determined the order of presentation of the tasks.

Procedure. Infants were tested individually in their own homes or at the University of Sussex crèche in the presence of a parent, guardian, or crèche-assistant. The infants were seated on their parent's lap or on a chair or high chair, and a table of the appropriate height was placed in front of them. For each object-manipulation task, the relevant eight objects were placed randomly on the table in front of the infants. The experimenter encouraged the infants to manipulate the objects with statements like "Here, these are for you to play with" and "Look at all this stuff." The experimenter then left the room, and the infants were given 2 min to manipulate the objects. Parents were instructed that should an object be dropped from the table or put out of reach of the infants, they were unobtrusively to replace it within touching distance. If no object manipulation occurred for 30 s or if the infants manipulated only one object for 30 s, the parents were instructed to encourage the infants to play with the whole set by passing a hand over the objects and saying "What can you do with all of these?" or words to that effect. Apart from such instances, there was no feedback from the experimenter. All four tasks were videotaped for later analysis.

Coding and scoring. Coding and scoring were as in previous studies that used the object-manipulation technique (e.g., Mandler et al., 1991; Rakison & Butterworth, 1998). Every object contacted by the infant, either by hand or with another object, and the order in which each object was touched were coded. In coding, the following rules, defined by Poulin-Dubois, Graham, and Sippola (1995), were observed: (a) if 10 s passed between touches, a break in the sequence was coded; (b) a touch was not considered part of a sequence if the attention of the infant

Table 1
Object-Manipulation Tasks and Exemplars Used in Experiment 1

Task	Animals	Vehicles
	Control task	
Animals vs. vehicles	Cow	All-terrain vehicle (ATV)
	Dog	Train
	Goose	Bus
	Walrus	Motorbike
	Matched-parts confound tasks	
Animals with legs vs. vehicles with wheels	Cow with legs on all sides	ATV with wheels on all sides
	Dog with legs on all sides	Train with wheels on all sides
	Goose with legs on all sides	Bus with wheels on all sides
	Walrus with legs on all sides	Motorbike with wheels on all sides
Animals with wheels vs. vehicles with legs	Cow with wheels on all sides	ATV with legs on all sides
	Dog with wheels on all sides	Train with legs on all sides
	Goose with wheels on all sides	Bus with legs on all sides
	Walrus with wheels on all sides	Motorbike with legs on all sides
	Across-categories confound task	
Animals, 2 with legs and 2 with wheels vs. vehicles, 2 with legs and 2 with wheels	Cow with legs on all sides	ATV with wheels on all sides
	Dog with legs on all sides	Train with wheels on all sides
	Goose with wheels on all sides	Bus with legs on all sides
	Walrus with wheels on all sides	Motorbike with legs on all sides

was drawn to an object by the parent or experimenter or if two objects from two different categories were touched simultaneously; (c) a single touch was coded if the same object was touched in succession or when the infant touched two objects from the same category simultaneously; and (d) if the infant was holding an object and touched other objects with it, the touches were counted as part of the sequence as long as the infant's attention was not restricted to the object being held.

Two judges independently coded 25% of the tasks (4 infants from each age group), and interrater reliability was obtained with two measures: (a) by calculating Pearson correlation coefficients between the run lengths scored by the two independent coders, and (b) by calculating a percentage agreement between the different objects touched as scored by the two coders. Overall coder reliability for the run lengths made by the infants was $r = .94$, and percentage reliability for objects touched by the infants was 93%. One judge coded the remaining tasks, and the coding made by that judge for the initial 25% of the tasks was used in the final analysis.

Procedures for analyzing sequential touching were taken from those developed by Mandler, Fivush, and Reznick (1987) and used subsequently in a number of categorizing studies (e.g., Bauer, Dow, & Hertsgaard, 1995; Mandler & Bauer, 1988; Mandler et al., 1991; Poulin-Dubois et al., 1995). The first measure determined whether sequential touching by groups of infants differed significantly from chance performance. The mean length of successive touches to the objects of each category was calculated for each child on each task and compared with one-tailed t tests to the run length expected by chance (1.75) if items from two sets of four objects were chosen at random. The appropriateness of one-tailed t tests was determined by their use in previous studies using the run length measure (e.g., Rakison & Butterworth, 1998; Mandler et al., 1991), and because the aim of the study was to assess whether infants perform above or at chance level, not below it. The mean run length analysis indicates whether infants touched sequentially objects from each category, but it does not provide detailed information about the type of touching that was made. For this reason, and to determine whether touching runs of three or four objects from the same category occurred by chance, a second measure of run length was carried out. Infants who touched systematically objects from one category were termed *single categorizers,* and infants who touched systematically objects from both categories were termed *dual categorizers.* The criterion for a categorizing run was the same as that used in previous research (e.g., Mandler et al., 1991; Starkey, 1981; Sugarman, 1983). A Monte Carlo program was used to determine the probability of occurrence of single and dual categorizing runs in 10,000 random draws. The program computed the number of categorizing runs of three or four items that would occur in a random draw repeated 10,000 times as a function of the number of touches made. Touches to the same object (i.e., repetitions) were allowed only if another object was touched between two touches to the same item and as long as there were at least three or four unique items in the categorizing run. As in previous studies, a cutoff point of $p < .10$ was used for the Monte Carlo analysis (e.g., Mandler et al., 1987; Mandler & Bauer, 1988).

Results

Run length analysis. Preliminary analysis revealed no significant statistical difference between the mean run lengths for gender or place of testing (i.e., home or crèche). The run length values for each sex and place of testing were therefore combined into a single mean run length score. The first run length analysis compared the mean run lengths for each task at every age level with the run length that would have been expected by chance (1.75). The mean run lengths for all the tasks and their associated one-tailed related t-test values are shown in Table 2.

It can be seen that 14-, 18-, and 22-month-old infants generated run lengths significantly greater than chance on the control task. Thus 14–22-month-old infants behaved systematically to the objects with wheels (vehicles) and to the objects with legs (animals). However, all three age groups produced run lengths at chance level when the parts of objects were modified within and between the categories. In other words, infants did not

Table 2
Mean Run Lengths and Associated t-Test Values for Four Manipulation Tasks in Experiment 1

Classification task	14 months	18 months	22 months
Control task			
Animals vs. vehicles	2.16 (2.68)**	2.70 (2.21)**	2.66 (2.18)*
Within-category confound			
Animals with legs vs. vehicles with wheels	1.71 (−0.43)	1.67 (−0.80)	2.40 (0.27)
Between-categories confound			
Animals with wheels vs. vehicles with legs	1.62 (−1.11)	2.09 (1.68)	1.94 (1.82)
Across-categories confound			
Animals (2 with legs, 2 with wheels) vs. vehicles (2 with legs, 2 with wheels)	1.62 (−0.96)	1.99 (1.35)	1.90 (0.74)
Objects with legs vs. objects with wheels	1.91 (0.73)	1.97 (0.91)	1.60 (−1.58)

Note. One-tailed t values ($df = 15$) of comparison to run length (1.75) are shown in parentheses.
$^{*}p < .05$. $^{**}p < .025$.

behave systematically to animals with confounded legs and vehicles with confounded wheels, nor to animals with confounded wheels and vehicles with confounded legs. Performance across all the age groups was also at chance level for objects coded as animals and vehicles on the across-categories confound. Thus, infants did not touch sequentially objects from the same category with different parts, for example, an animal with legs and an animal with wheels. Infants could also have touched these objects on the basis of parts, for example, by touching sequentially those objects with legs. However, across the three age groups, the run lengths for these alternative groupings were at chance level.

The run length analysis showed whether infants behaved systematically to the object sets—that is, whether they tended sequentially to touch related objects—but it did not allow direct comparison of performance across tasks and age groups. The run lengths were therefore investigated further with two-way mixed-design analysis of variance (ANOVA). The main analysis had three levels of age (14, 18, and 22 months) as a between-subjects variable and four types of task (control task and within-, between-, and across-categories confounds) as a within-subjects variable. The analysis revealed that the only reliable effect was for task, $F(3, 135) = 4.01$, $p < .001$. Tukey's honestly significant difference test ($p < .05$) revealed that the mean run lengths generated on the control task ($M = 2.50$) were significantly higher than the mean run lengths on the three confound tasks (within-category confound: $M = 1.92$; between-categories confound: $M = 1.89$; across-categories confound: $M = 1.83$). Hence, across the three age groups, infants' run lengths were longer when structural part relations of objects were normal than when they were violated.

Monte Carlo analysis. The run length analysis did not reveal which category was touched, how many objects within any given category were touched, or how many infants engaged in categorization. To address this issue, we used a Monte Carlo program to compare the number of infants who made categorizing runs of three or four touches with that expected at chance level. Table 3 shows the percentage of infants classified as single (a minimum three or four sequential touches to items from only one category) or dual categorizers (a minimum three or four sequential touches to items from each category) and the mean length of any categorizing runs made.

From an initial analysis of the data, it is worth noting that the infants' performance on the control task, in terms of mean run length and percentage of categorizers, was considerably greater than on the other four tasks. Thus the mean run lengths on the control task for single and dual categorizers were 5.0 and 4.6, respectively, which compare to mean run lengths of 3.9 and 3.5 for single and dual categorizers on the other four tasks. This difference corresponds to the results of the run length analysis that showed that infants generated longer run lengths on the control task than on the other four tasks. The data show also that although many of the run lengths were well above the minimum of 3, infants in the confound tasks often produced run lengths that approached this figure (11 of the 14 were below 4, and 6 of the 14 were 3.5 or below). This suggests that infants did not explore relations among objects but made a series of brief contacts with different items. The percentage of infants classified as single or dual categorizers provides additional evidence that this kind of behavior was common in the confound tasks: Across the three age groups, the total percentage of infants classified as single and dual categorizers was below 50% on 6 conditions (out of 12) of the confound tasks.

Analyses of object salience. The Monte Carlo analysis indicated that the majority of infants were single rather than dual categorizers. As in previous studies, the low number of dual categorizers raises two questions: First, did single categorizers make sequential touches only to one category (e.g., vehicles), and second, was touching the result of a particularly salient object or category? The second question is especially important because it is possible that infants' categorization was driven by the novelty of the confounded objects. Several analyses of salience were carried out to assess whether infants' touching (particularly single categorizing) resulted from the salience of an object or type of object (e.g., animals). Following the format developed by Mandler and her associates (Mandler et al., 1987), the most salient category was defined as (a) the object set most often categorized by the single categorizers or (b) the object

Table 3
Percentage of Categorizers and Mean Categorizing Run Lengths on Four Manipulation Tasks

Classification task	14 months %	14 months *M*	18 months %	18 months *M*	22 months %	22 months *M*
Control task						
Animals vs. vehicles						
Single	50	3.8	50	5.4	44	5.7
Dual	13	4.0	13	5.8	38	4.1
Total	63		63		82	
Within-category confound						
Animals with legs vs. vehicles with wheels						
Single	44	3.3	38	3.7	38	5.1
Dual	0	0.0	6	3.3	19	4.1
Total	44		44		57	
Between-categories confound						
Animals with wheels vs. vehicles with legs						
Single	25	3.8	38	4.6	56	3.1
Dual	0	0.0	13	3.8	6	4.0
Total	25		51		62	
Across-categories confound						
Animals (2 with legs, 2 with wheels) vs. vehicles (2 with legs, 2 with wheels)						
Single	13	3.0	31	4.4	31	4.6
Dual	6	3.5	25	3.9	0	0.0
Total	19		56		31	
Objects with legs vs. objects with wheels						
Single	56	3.7	44	4.1	13	4.0
Dual	6	3.0	13	3.0	6	3.0
Total	62		57		19	

set touched first by the dual categorizers. The first analysis used chi-square tests to examine the number of infants who chose each object group (category) within each task. Across all three age groups, there was a significant preference for vehicles over animals on the within-category confound, $\chi^2(1, N = 23) = 8.96$, $p < .005$, and on the across-categories confound, $\chi^2(1, N = 17) = 7.35$, $p < .01$. There was no significant preference for either category on the remaining tasks.

A second test of salience used two-tailed related t tests to analyze the number of touches to animals and vehicles in the four tasks at every age level (14, 18, and 22 months). The tests revealed that 18-month-olds made significantly more touches to vehicles than animals on the between-categories confound (vehicle $M = 5.4$; animal $M = 3.9$), $t(16) = 2.35$, $p < .05$, and the across-categories confound (vehicle $M = 5.3$; animal $M = 3.6$), $t(16) = 2.57$, $p < .05$. In addition, 22-month-olds made significantly more touches to vehicles ($M = 5.9$) than animals ($M = 3.8$) on the within-category confound, $t(16) = 2.35$, $p < .05$. There were no other significant effects on any task or at any age level. Hence, infants found vehicles more salient than animals on individual tasks but did not find any category or part systematically more salient.

A third test of salience used two-way repeated measures ANOVA to compare the number of touches made by infants to each of the stimuli on the different tasks. The rationale was to examine whether confounded stimuli were more salient and to test for any effect due to the choice of stimuli that were confounded. The main design contrasted four types of task (control and within-, between-, and across-categories confounds) and four types of stimuli. Separate analyses were performed for the animal and for the vehicle stimuli. The analysis for the animal stimuli showed that the number of touches to the animal exemplars was not uniformly distributed, $F(3, 141) = 3.25$, $p < .01$. A post hoc Tukey test ($p < .05$) on the number of touches showed that significantly fewer touches were made to the walrus ($M = 0.69$) than the dog ($M = 1.08$), the cow ($M = 1.10$), and the goose ($M = 1.20$). There were no further differences between the number of touches to the animal exemplars. There was also a main effect for task, $F(3, 141) = 3.11$, $p < .025$. A post hoc Tukey test ($p < .05$) indicated that significantly more touches were made on the control task ($M = 6.2$) than the within-category confound ($M = 4.4$) and the across-categories confound ($M = 4.1$). There were no other significant differences among tasks, and the interaction of the variables was not significant. The analysis for the vehicle stimuli showed that the numbers of touches were not equally distributed across tasks, $F(3, 141) = 2.65$, $p < .05$. A post hoc Tukey test ($p < .05$) on the number of touches made on each task indicated that significantly more touches were made in the control task ($M = 5.9$) than in the within-category confound ($M = 4.7$) and the across-categories confound ($M = 4.5$). There were no other significant differences among tasks, nor was there a main effect for vehicle stimuli or a significant interaction of the two variables. Hence, no single stimulus within a category was touched more than any other. This suggests that the choice of stimuli that were confounded did not affect categorization. The vehicles were treated as more salient by certain age groups on three tasks; however, there was no consistent effect for age or task.

Discussion

The finding that 14-, 18-, and 22-month-old infants classified animals and vehicles with parts in a normal configuration is consistent with the theory that they may use a single object part to make category membership decisions. However, infants' behavior on the three confound tasks suggests that they do not attend to object parts in isolation; that is, infants did not categorize objects from the animal and vehicle domains when the normal structure of those objects was violated. These data imply that 14–22-month-olds do not categorize by judging solely which objects possess the same parts; rather, they may well attend to part differences and the configuration of parts. This conclusion is compatible not only with Tversky (1989), who found that children do not recognize objects with uncommon canonical contours, but also with Madole, Oakes, and Cohen (1993), who claimed that 1–2-year-olds respond to the readily accessible perceptual features of objects that comprise structural properties.

There are a number of problems with the design of the confound tasks in this study. First, the tasks measured infants' responses to part structure through a violation of two aspects of that property, namely one where the relationship among parts was violated (e.g., legs in uncommon position with other legs) as well as the relationship between parts and the remainder of the object (e.g., legs in uncommon position to object body). It is possible that the effect of just one of these alterations is sufficient to disrupt infant attention to part structure. Second, infants were presented only with novel objects in the confound tasks; that is, all the stimuli were confounded. A better test of infants' basis for categorization might be to explore whether they treat equivalently objects with violated part configuration and objects with normal part configuration. Third, infants were presented only with different-parts contrasts, that is, animals versus vehicles. It remains to be seen whether infants' categorization of objects with matching parts (e.g., legs in animals and furniture) is affected by the structural configuration of parts.

Experiment 2 was designed to address these issues. Responses to two distinct violations of structural properties were measured on same-parts (animals and furniture) and different-parts (animals and vehicles) contrasts: (a) The relationship within the substructure of parts was preserved but not the relationship between the part and the rest of object; for example, the four legs of a cow were moved, as a unit, into a novel orientation. (b) Neither the relationship within the parts or the relationship between the parts and the remainder of the object was preserved; for example, each of the four legs of a cow was moved into a novel orientation tangential to the other three legs. In contrast to Experiment 1, two stimuli from each category (e.g., animals) were confounded rather than all four stimuli. For the first kind of violation, it was reasoned that infants would treat confounded objects as equivalent to unmodified objects if the structure of parts themselves (e.g., four legs in a quadrapedal configuration) is crucial to category membership. For the second kind of violation, it was reasoned that infants would treat confounded objects as equivalent to unmodified objects if they attend to parts independently and not to the structure of those parts. An alternative possibility was that infants would attend to structural features of objects independently and therefore treat those objects with the same configuration of parts as equivalent irrespective of the parts involved.

Experiment 2

Method

Participants. Forty-eight infants participated in the experiment: 16 with a mean age of 14 months 15 days (range = 13 months 17 days to 14 months 23 days), 16 with a mean age of 17 months 20 days (range = 17 months 6 days to 18 months 16 days), and 16 with a mean age of 22 months 12 days (range = 21 months 15 days to 22 months 25 days). There were equal numbers of boys and girls in the 14- and 18-month-old groups. In the 22-month-old group there were 7 girls and 9 boys. Eight additional infants were tested but were not included in the study: 2 infants because of fussiness or crying, 4 infants for not engaging in the tasks (touching fewer than three objects), and 2 infants as a result of experimenter error. Infants were drawn from two sources: Thirty-nine of the infants were recruited from a pool of volunteer parents who had responded to an advertisement for an unrelated experiment, and 9 of the infants, 3 in each age group, were recruited at the University of Sussex crèche facility.

Stimuli. The stimuli were drawn from three categories: animals, vehicles, and furniture. The animals were a cow, a dog, a goose, and a walrus; the vehicles were an ATV, a train, a bus, and a motorbike; and the furniture was a chair, a table, a bed, and a cabinet. All of the exemplars were 3-D realistic scale models and ranged in size between 4 and 6 cm in length and 2 and 4 cm in height. Every animal and furniture exemplar possessed legs, and every vehicle exemplar possessed wheels. The parts of the exemplars within each category varied in form and number (e.g., a goose had two legs, a walrus had four flippers). The animals and furniture were made from rubber or plastic and had no moving parts. The vehicles were made from metal and had no moving parts. The animal, furniture, and vehicle domains were chosen because they allowed for a contrast of stimuli with same parts and a contrast of stimuli with different parts. A description of the stimuli is presented in Table 4.

Novel versions of four of the eight stimuli in each task were generated by attaching, detaching, dividing, and moving particular parts (legs or wheels). Stimuli were altered to affect structural part relations in one of two ways: (a) Parts (legs or wheels) were moved as a complete unit into the opposite orientation to that found normally; for example, the cow had four legs, in the normal configuration, but they were attached to its back and pointing upward. Thus legs on animals could still support, and wheels on vehicles could still roll. (b) As in Experiment 1, parts were divided into four individual units (e.g., four separate legs), and then each part was situated in a position tangential to the host object and to the other parts; for example, the cow had one leg pointing sideways on each side of its stomach, one pointing upward, and one pointing downward. Thus, legs could not offer support nor could wheels roll. The first type of confound, which assessed infants' attention to a single violation between an object and its parts, was termed the *orientation confound.* The second type of confound, which assessed infants' attention to a more complete violation between an object and its parts, was termed the *configuration confound.* Figure 1 illustrates examples of both types of confound.

The experiment was composed of four manipulation tasks. Two tasks contrasted animal and vehicle exemplars, and two tasks contrasted animal and furniture exemplars. One task contrasted animals and vehicles,

Table 4
Object-Manipulation Tasks and Exemplars Used in Experiment 2

Classification task	Animals	Vehicles
	Orientation confound: Different parts	
Animals vs. vehicles	Cow with legs on back Dog with legs on back Goose Walrus	All-terrain vehicle (ATV) with wheels on roof Train with wheels on roof Bus Motorbike
	Orientation confound: Same parts	
Animals vs. furniture	Cow with legs on back Dog with legs on back Goose Walrus	Bed with legs on side[a] Chair with legs on side[a] Cabinet Table
	Configuration confound: Different parts	
Animals vs. vehicles	Cow with legs on all sides Dog with legs on all sides Goose Walrus	ATV with wheels on all sides Train with wheels on all sides Bus Motorbike
	Configuration confound: Same parts	
Animals vs. furniture	Cow with legs on all sides Dog with legs on all sides Goose Walrus	Bed with legs on all sides Chair with legs on all sides Cabinet Table

[a]Legs were reattached on the sides of the bed and chair rather than the top because it was not possible to put all four legs, as a unit, onto the top of these objects.

with the parts of two exemplars from each category confounded in their orientation. Hence, the stimuli were composed of four animals (a cow with legs on back, a dog with legs on back, a goose, a walrus) and four vehicles (an ATV with wheels on roof, a train with wheels on roof, a bus, a motorbike). A second task was a contrast of animals and furniture, with the parts of two exemplars from each category confounded in their orientation. This task was composed of four animals (a cow with legs on back, a dog with legs on back, a goose, a walrus) and four items of furniture (a bed with legs on side, a chair with legs on side, a cabinet, a table). The legs of the two confounded furniture exemplars were placed on the sides of the objects so that they might still be perceived as potentially offering support. The legs were not re-attached to the top of the bed and chair because it was not possible to put all four legs, as a unit, into this position.

A third task contrasted animals and vehicles, with the parts of two exemplars from each category confounded in configuration. The stimuli were four animals (a cow with legs on four sides, a dog with legs on four sides, a goose, a walrus) and four vehicles (an ATV with wheels on four sides, a train with wheels on four sides, a bus, a motorbike). The legs and wheels could therefore no longer be perceived as offering support. A fourth task involved a contrast of animals and furniture, with two exemplars from each category confounded in configuration. The stimuli were four animals (a cow with legs on four sides, a dog with legs on four sides, a goose, a walrus) and four items of furniture (a bed with legs on four sides, a chair with legs on four sides, a cabinet, a table). It was not possible to counterbalance Tasks 1 and 2 by confounding the walrus, the goose, the motorbike, and the bus because legs or wheels could not be placed in appropriate positions on those objects. For similar reasons, Tasks 3 and 4 were not counterbalanced by confounding the walrus, the goose, the motorbike, and the bus. Although Experiment 1 showed that the walrus was less salient than the other animal stimuli, it has previously been found that infants' touching to these animal and vehicle stimuli shows no effect for salience (Rakison & Butterworth, 1998). Hence, although it was possible that infants' touching to the animals was lowered by the walrus, partial counterbalancing was considered to be an adequate control. Each infant was presented with all four tasks. A Latin square determined the order of presentation of the tasks.

Procedure, coding, and scoring. The procedure was the same as that in Experiment 1, with one exception. For the two orientation confound tasks, the confounded stimuli were placed in front of the infant in their normal body orientation. Thus, the confounded parts (i.e., legs or wheels) were inverted; for example, the dog's head and body were in the correct orientation but its legs were inverted. The other stimuli (normal parts) were presented in a random manner. This modification was used to examine whether infants would re-invert confounded objects even though this would mean that the body of the object would appear upside-down. Such behavior might suggest that infants have expectations about, or are sensitive to, the position (i.e., orientation) of particular part structures.

All tasks were videotaped and scored in the same format as in Experiment 1. The primary coder was not the same one who was the primary coder in Experiment 1. Overall coder reliability for the infants' run lengths was $r = .93$, and percentage reliability for objects touched by infants was 92%. In addition, coders scored the number of infants who inverted a confounded stimulus into the correct orientation (e.g., legs vertical and in contact with a horizontal surface) and the objects inverted by the infants. Overall coder reliability for the objects inverted by the infants was $r = 1.00$.

Results

Run length analysis. Preliminary analysis revealed no significant statistical difference in the mean run lengths for gender

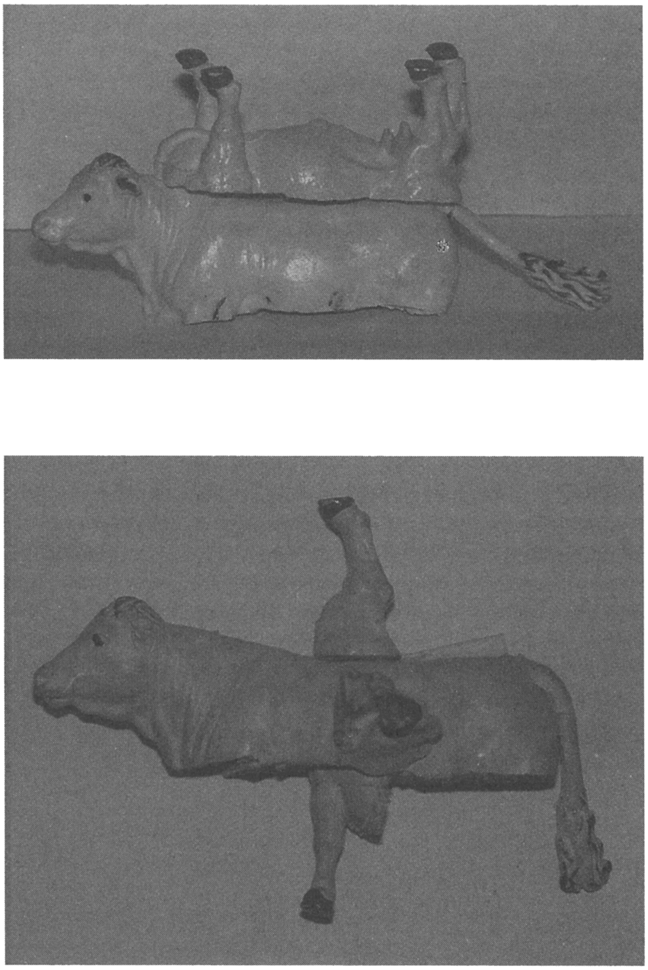

Figure 1. Examples of stimuli used in Experiment 2: Cow with legs in novel orientation (top panel) and cow with legs in novel configuration (bottom panel).

or place of testing (i.e., home or crèche). The run length values for each sex and place of testing were therefore combined into a single mean run length score. The first run length analysis compared the mean run lengths for each task at every age level with the run length that would have been expected by chance (1.75). The mean run lengths for all of the tasks and their associated one-tailed related *t*-test values are shown in Table 5.

It can be seen that 14-, 18-, and 22-month-old infants generated run lengths significantly greater than chance to animals and vehicles on the different-parts orientation confound. Thus infants behaved systematically to objects with the same-parts and different-part structures; for example, they touched sequentially a dog with legs in a novel orientation and a goose with legs in a normal orientation. However, on the same-parts orientation confound, 14- and 18-month-olds' mean run lengths were at chance level to objects as animals (legs) and furniture (legs). In contrast, on the same task 22-month-old infants generated run lengths significantly greater than chance to objects as animals (legs) and furniture (legs). Thus, 22-month-old infants behaved systematically to animals and furniture even when the legs of half the stimuli were confounded in orientation.

Infants in the 14- and 18-month-old groups did not generate mean run lengths significantly greater than chance on the different-parts configuration confound. However, 22-month-olds' mean run lengths were significantly greater than chance to stimuli as animals (legs) and vehicles (wheels). Thus 22-month-olds behaved systematically to objects with the same parts in different configurations; for example, grouping a dog with inverted legs and a goose with unmodified legs. Finally, infants in all three age groups made run lengths at chance level to the animals and furniture on the same-parts configuration confound. In other words, they failed systematically to touch animals with legs in a novel configuration and animals with unmodified legs. On all four tasks, infants generated mean run lengths at chance level toward objects on the basis of part structure; for example, they did not group together animals and furniture that had legs in an uncommon configuration.

The run lengths were investigated further with a two-way mixed-design ANOVA. The first analysis examined whether there was a difference between touches to the two kinds of parts contrast (same-parts and different-parts). The analysis had three levels of age (14, 18, and 22 months) as a between-subjects variable and two types of stimuli (same-parts and different-parts) as a within-subjects variable. The analysis revealed significant main effects for age, $F(2, 45) = 4.21$, $p < .025$; type of stimuli, $F(1, 45) = 7.02$, $p < .01$; and also an interaction effect, $F(2, 45) = 5.19$, $p < .01$. To investigate the main effect of age further, we performed a Tukey test on the data ($p < .05$). The test indicated that 22-month-olds ($M = 3.13$) generated significantly longer run lengths than 14- ($M = 2.06$) and 18-month-olds ($M = 2.25$). The run lengths of the two younger age groups were not significantly different. A further Tukey test on the means for stimuli indicated that significantly longer run lengths were generated on the tasks contrasting animals and vehicles ($M = 2.82$) than on the tasks contrasting animals and furniture ($M = 2.14$). The interaction was interpreted through analysis of the mean run lengths across the age groups and stimuli. The data suggest that 14- and 18-month-olds behaved similarly with the two types of parts contrast (same and different), and 22-month-olds performed quite differently in each contrast. The mean run lengths generated by 22-month-olds suggest that they made more touches when there was a part difference among objects ($M = 4.04$) than when there was no part difference among objects ($M = 2.21$).

Monte Carlo analysis. As in Experiment 1, a Monte Carlo analysis was conducted. Table 6 shows the percentage of infants classified as single or dual categorizers and the mean lengths of any categorizing runs made.

It is worth noting that the total percentage of infants classified as categorizers was equal to or greater than 50% on all tasks; that is, the majority of infants categorized. However, more infants on each task were classified as single categorizers than dual categorizers, which suggests that infants predominantly generated run lengths of three or more touches to any one of the available categories. The data indicate that the infants' performance, in terms of percentage of single and dual categorizers, improved with age. Across the four tasks, the mean percentage of infants classed as categorizers, based on the total percentage

Table 5
Mean Run Lengths and Associated t-Test Values for Four Manipulation Tasks in Experiment 2

Classification task	14 months	18 months	22 months
Orientation confound: Different-parts contrast			
Animals vs. vehicles	2.14 (2.37)*	2.20 (2.37)*	3.86 (2.16)*
Normal parts vs. inverted parts	1.83 (0.33)	1.75 (0.07)	1.83 (0.75)
Orientation confound: Same-parts contrast			
Animals vs. furniture	2.13 (1.53)	2.07 (1.23)	2.36 (2.87)*
Normal parts vs. inverted parts	1.46 (−3.09)	1.84 (1.49)	1.84 (0.56)
Configuration confound: Different-parts contrast			
Animals vs. vehicles	2.05 (1.41)	2.40 (1.73)	4.23 (2.28)*
Normal parts vs. confound parts	1.64 (−1.08)	2.00 (1.17)	1.68 (−0.61)
Configuration confound: Same-parts contrast			
Animals vs. furniture	1.96 (1.02)	2.28 (1.96)	2.06 (1.86)
Normal parts vs. confound parts	1.94 (0.93)	1.71 (−0.32)	1.90 (1.11)

Note. One-tailed t values (df = 15) of comparison to run length (1.75) are shown in parentheses.
$^* p < .05$.

of infants classed as single and dual categorizers, increased systematically from 56% at 14 months, to 72% at 18 months, and then to 80% at 22 months. However, the mean run lengths across the four tasks do not match this linear trend. Thus the 14-month-olds (M = 5.6) and the 22-month-olds (M = 6.1) classified as single categorizers generated similar mean run lengths, and the 18-month-olds similarly classified generated run lengths that were considerably lower (M = 4.3). On the other hand, of the infants classified as dual categorizers, 18-month-olds (M = 4.6) generated notably higher mean run lengths than 14- (M = 3.6) and 22-month-olds (M = 3.9). It should be noted, however, that the mean run lengths of 14-month-olds classified as dual categorizers are based on three tasks, whereas the mean run lengths of 18-month-olds classified as dual categorizers are based on only two tasks (i.e., no infants were classified as dual categorizers on certain tasks).

Table 6
Percentage of Categorizers and Mean Categorizing Run Lengths on Four Manipulation Tasks

	14 months		18 months		22 months	
Classification task	%	M	%	M	%	M
Orientation confound						
Animals vs. vehicles						
Single	56	5.8	63	4.1	50	7.9
Dual	6	3.0	6	4.5	25	4.6
Total	62		69		75	
Animals vs. furniture						
Single	44	7.0	56	4.2	88	4.8
Dual	13	4.4	19	4.8	6	3.5
Total	57		75		94	
Configuration confound						
Animals vs. vehicles						
Single	50	4.5	69	4.3	69	6.6
Dual	6	3.5	0	0.0	6	3.6
Total	56		69		75	
Animals vs. furniture						
Single	50	5.3	75	5.0	44	4.9
Dual	0	0.0	0	0.0	31	4.0
Total	50		75		75	

Analyses of part orientation. A number of analyses were performed to investigate infants' behavior toward the confounded objects presented to infants with their parts upside-down and their body (trunk) in a normal orientation (see the *Procedure, coding, and scoring* section). In the first analysis a chi-square goodness-of-fit test was used to examine the number of infants in each age group who inverted at least one exemplar in both orientation confound tasks. The test was significant, $\chi^2(2, N = 19) = 7.72, p < .05$, indicating that the number of infants who inverted stimuli was not equally distributed across the age groups. Further examination of the data showed that the number of 22-month-olds (12) who inverted the confounded objects was considerably higher than the number of 14- and 18-month-olds (3 and 4, respectively) who made the same response.

To examine the number of inversions made by infants in each task, we performed a second analysis. The normal approximation to the binomial distribution with a correction for continuity was calculated for the number of confounded objects inverted as a function of the total number of confounded exemplars contacted. Given that the confounded exemplars could be replaced on a horizontal surface in at least four orientations (normal, inverted, left side, right side), the chance probability that an exemplar would be placed in the correct orientation (e.g., legs vertical and in contact with horizontal surface) was set at .25. This is a more stringent criterion than it appears because most of the objects could be placed on more than four sides.

Table 7
Mean Touches for Each Category Type and t-Test Values

	14 months		18 months		22 months	
Task	Mean touches	$t(15)$	Mean touches	$t(15)$	Mean touches	$t(15)$
			Orientation confound			
Animals	3.8	2.44*	3.6	1.85	3.8	2.21*
Vehicles	6.2		6.3		7.0	
Animals	5.2	0.94	4.6	0.06	4.9	2.22*
Furniture	4.2		4.6		7.0	
			Configuration confound			
Animals	4.1	2.37*	3.3	2.28*	4.4	2.51**
Vehicles	6.6		4.9		8.9	
Animals	5.4	0.00	3.6	2.60**	4.8	1.51
Furniture	5.4		6.2		6.1	

* $p < .05$. ** $p < .025$.

The tests revealed that 14- and 18-month-olds performed at, or below, chance level in terms of the number of stimuli they inverted. However, the number of confounded stimuli inverted by 22-month-olds was significantly greater than that expected by chance on the animals and vehicles contrasts ($z = 2.13$, N = 39, Y = 16, $p < .025$) and the animals and furniture contrasts ($z = 2.61$, N = 44, Y = 19, $p < .005$).

Analyses of object salience. As in the previous experiment, several analyses of salience were carried out. The first analysis used chi-square tests to examine the number of infants who chose each category within each task. The results indicated that across all three age groups there was no preference for a particular object set. A second test of salience used two-tailed related t tests to examine the number of touches to each object set in each task at every age (14, 18, and 22 months). The results of the tests are presented in Table 7. With the exception of 18-month-olds on the orientation confound task, significantly more touches were made to vehicles than animals in every task and at every age. This preference for vehicles over animals is different than that found in previous studies where animal and vehicle stimuli were touched equally (i.e., Rakison & Butterworth, 1998). The other result of note is that 18-month-olds made significantly more touches to the furniture ($M = 6.2$) than to the animals ($M = 3.6$) in the configuration confound task. A third test of salience used two-way dependent ANOVAs to compare the number of touches made by infants to the animals, vehicles, and furniture on the four different tasks. The main design contrasted four types of tasks (same- and different-parts orientation confound, same- and different-parts configuration confound) and four types of stimuli. The analysis for the animal stimuli showed that the number of touches to the animal exemplars was not uniformly distributed, $F(3, 141) = 5.32$, $p < .005$. A post hoc Tukey test ($p < .05$) indicated that significantly more touches were made to the goose ($M = 1.32$) than the walrus ($M = 0.80$) and the dog ($M = 0.99$), and significantly more touches were made to the cow ($M = 1.21$) than to the walrus ($M = 0.80$). There were no further differences in the number of touches to the animal exemplars, nor was there a main effect for task or a significant interaction between the two variables. The analyses for the vehicle stimuli and for the furniture stimuli revealed no significant effects.

Discussion

The results of Experiment 2 suggest that 1–2-year-old infants attend to the part structure of objects in category membership decisions. The data seem initially to support the findings of Rakison and Butterworth (1998) in that 14- and 18-month-olds behaved systematically toward categories with different parts (i.e., animals with legs and vehicles with wheels) but did not do so toward categories with the same parts (i.e., animals with legs and furniture with legs). This implies that parts may act independently as the basis for infants' categorization. However, the behavior of 14- and 18-month-olds on the various confound tasks indicated that categorization was affected considerably by object structure. At 14 and 18 months, for example, infants grouped objects with matching parts (e.g., animals) when the structural relationship between a part and the rest of the object was violated in orientation alone, but they did not do so when the relationship between a part and the remainder of the object was violated in configuration. Hence, infants as young as 14 months may have developed some of the processing biases possessed by adults; that is, they treat objects with parts in an unusual orientation as equivalent to objects with the same parts in a normal orientation. In a similar manner, we might expect that adults would consider a dog on its back and with its legs in the air to be the same as a dog that stands, but we would not consider a dog with legs in a biologically unrealizable configuration to be the same as a dog that stands.

The 22-month-old infants categorized quite differently from the younger age groups. In addition to the categorizing behavior displayed by 14- and 18-month-olds, the 22-month-old infants classified objects with matching parts (i.e., animals and furniture) when orientation alone was confounded, and they categorized objects with different parts (i.e., animals and vehicles) when orientation and configuration were confounded. Thus, 22-month-old infants' categorization is not affected by a violation of part structure that does not interfere with the normal configuration of the object. However, their categorization of objects with matching parts (e.g., all objects with legs) is affected by a violation of part structure that interferes with the normal configuration. By 22 months, infants treated violations that affected part structure configuration as equivalent to normal configurations, though they did so only when there were part differences between the objects (i.e., some had wheels and some had legs). The analyses of infants' behavior in response to the orientation confounds suggest that 22-month-olds may be sensitive to the function of object parts. For example, they inverted objects that were presented with their parts upside-down on both the same- and the different-parts contrasts. This implies that by 22 months, infants have expectations about the normal orientation of parts and seek to place them in this orientation.

It is possible that infants in this experiment, and in previous experiments that used the same stimuli (i.e., Rakison & Butterworth, 1998), more easily categorized animals and vehicles than animals and furniture because of textural differences among the stimuli. For instance, the animal and the furniture stimuli were made from dull plastic or rubber, whereas the vehicle stimuli were made from shiny metal. Thus, infants' categorization of animals and vehicles, and their preference for vehicles in certain tasks in Experiment 1 and nearly all of the tasks in Experiment 2, may have resulted from visual (shiny–nonshiny) or from visual–tactile (metallic–nonmetallic) differences in the stimuli.[1] Should this possibility be realized, it would raise serious doubts as to whether infants actually attend to object parts and structural configuration as the basis for categorization. To examine whether texture differences among the stimuli were responsible for infants' categorization, we performed a further experiment that counterbalanced visual and visual–tactile cues among the stimuli.

Experiment 3

Method

Participants. There were 48 infants in the experiment: 16 with a mean age of 14 months 4 days (range = 13 months 14 days to 14 months 15 days), 16 with a mean age of 17 months 28 days (range = 17 months 19 days to 18 months 13 days), and 16 with a mean age of 22 months 4 days (range = 21 months 24 days to 22 months 10 days). There were 7 girls and 9 boys in the 18-month-old group, and an equal number of boys and girls in the 14- and 22-month-old groups. Eleven additional infants were tested but were not included in the study: 6 because of fussiness and 5 because of experimenter error. Infants' names were obtained through birth announcements in the local newspaper. Parents were contacted by letter and by telephone.

Stimuli, procedure, coding, and scoring. Two object-manipulation tasks were used: (a) The "all plastic" task was composed of four plastic animals (cow, cat, elephant, bird) and four plastic vehicles (train, cement truck, dumpster, motorbike); (b) The "half and half" task was composed of two plastic vehicles (train, dumpster), two metallic vehicles (van, ATV), two plastic animals (cow, bird), and two metallic animals (cat, elephant). (Because it proved difficult to find metal animal stimuli, hard plastic animals were covered with metallic paint. This gave the stimuli the shiny appearance and harder texture of metal. In an informal study of the perceptual appearance of the objects, 18 of 20 adults judged them to be metallic.) Every animal possessed legs, and every vehicle possessed wheels. The wheels were glued so that they could not roll. Each infant took part in both tasks, and the order of presentation was counterbalanced. The procedure, coding, and scoring were the same as in Experiment 1, except that each infant was tested in the laboratory. Overall coder reliability for the run lengths was $r = .94$, and percentage reliability for objects touched by the infants was 92%.

Results

Mean run length values were calculated for the two tasks and were compared with the run length expected by chance (1.75). The means and their associated t values are shown in Table 8. It can be seen that with the exception of the 18-month-olds on the task that contrasted plastic animals and plastic vehicles, all three age groups generated mean run lengths significantly greater than chance to objects with legs (animals) and objects with wheels (vehicles). Thus, infants tended systematically to touch animals and vehicles that shared the same visual–tactile texture (i.e., all-plastic task), and they touched systematically animals and vehicles that were balanced for visual–tactile texture (e.g., half-and-half task). It can also be seen that even though infants were provided with the option to categorize by attending to textural cues, all three age groups' run lengths to plastic and metallic objects were at chance level. Table 9 displays the percentage of infants who were classified as either single or dual categorizers by the Monte Carlo analysis. For all three age groups combined, 69% of the infants on the all-plastic task and 73% of the infants on the half-and-half task displayed categorizing behavior to objects on the basis of parts. However, only 42% showed such behavior to objects on the basis of a plastic versus metal distinction.

Analyses of salience revealed that the 22-month-olds made more touches to the vehicle category ($M = 6.4$) than to the animal category ($M = 4.6$), $t(15) = 2.02, p < .05$. In addition, the 22-month-olds made more touches to the metallic objects ($M = 6.9$) than the plastic objects ($M = 5.0$), $t(15) = 3.18$, $p < .005$. One-way related ANOVA revealed that the number of touches to the animal exemplars on the all-plastic task were not uniformly distributed, $F(3, 141) = 3.74, p < .025$. Pairwise comparisons ($p < .05$) found that significantly more touches were made to the cat ($M = 1.42$) than to the cow ($M = 0.98$) and the elephant ($M = 0.85$). The number of touches to the animal exemplars on the half-and-half task were also not uniformly distributed, $F(3, 141) = 2.66, p < .05$. Pairwise comparisons ($p < .05$) showed that significantly more touches were made to the cat ($M = 1.56$) than to the bird ($M = 0.98$). Finally, 18-month-olds made significantly more touches to the van ($M = 2.06$) in the half-and-half task than to the cement truck (M

[1] It is not clear why infants in Experiment 1 and Experiment 2 showed a preference for vehicles over animals when the same toy vehicles were found previously not to be overly salient (Rakison & Butterworth, 1998). The most likely cause is that modifying the stimuli by moving parts into a novel orientation or configuration affected differentially infants' perception of the animals and vehicles. One possible, albeit speculative, explanation is that vehicles' structure is more contingent on their parts in comparison to animals. For example, the legs of an animal can be found in a multitude of positions—when the animal is sleeping, for instance—whereas the wheels of a vehicle are quite fixed in their position. Consequently, infants may have found the novel vehicle structures to be more unusual, and therefore more salient, than those of the novel animal structures.

Table 8
Mean Run Lengths and Associated t-Test Values for Two Manipulation Tasks in Experiment 3

Classification task	14 months	18 months	22 months
All-plastic task (animals vs. vehicles)	2.18 (1.95)*	2.10 (0.97)	2.04 (1.78)*
Half-and-half task (animals vs. vehicles)	2.74 (1.76)*	2.74 (3.15)***	2.87 (3.38)***
Plastic objects vs. metallic objects	1.99 (0.99)	1.85 (0.47)	1.71 (0.28)

Note. One-tailed t values (df = 15) of comparison to run length (1.75) are shown in parentheses.
* $p < .05$. *** $p < .0025$.

= 0.94) in the all-plastic task, $t(15) = 2.76$, $p < .01$. There were no other significant effects.

Discussion

The results of Experiment 3 go some way to eliminate textural differences among the stimuli as an explanation for infants' behavior in Experiments 1 and 2. Not only did 14- and 22-month-old infants categorize animals and vehicles that had the same visual–tactile properties, but all three age groups categorized on the basis of parts (i.e., superordinate domain) rather than texture when given a choice between the two. This suggests that infants do not attend to the textural properties of objects prior to parts or object structure. These results are generally consistent with Van de Walle and Hoerger (1996), who found that young infants sorted animal-like and vehicle-like objects—equated for size, shape, texture, and color—on the basis of curvilinear versus rectilinear part structure. The results are also in accord with Rakison and Butterworth (1998), who found that 14- and 18-month-olds grouped together animals and vehicles on the basis of parts even though they differed in textural characteristics (e.g., a train with legs and a walrus).

The behavior of the 18-month-olds on the plastic animals versus plastic vehicles task is somewhat surprising given that the 14- and 22-month-olds categorized successfully on the same task: It is unusual for one age group to fail on this kind of categorization task when a younger age group succeeds. More puzzling, perhaps, is that the 18-month-olds categorized by attending to parts when textural cues varied across and within the categories (half-and-half task) but did not categorize on the same basis when textural cues were equivalent across and within the categories (all-plastic task). In any case, the 14- and 22-month-olds' data, as well as that from the 18-month-olds on the half-and-half task, imply that infants do not attend to visual or visual–tactile cues in category membership decisions. Rather, these results support the notion that infants categorize by attending to parts and object structure.

Table 9
Percentage of Single and Dual Categorizers in Experiment 3

Categorization task	14 months	18 months	22 months
All-plastic task (animals vs. vehicles)			
Single	75	56	50
Dual	0	6	19
Total	75	62	69
Half-and-half task (animals vs. vehicles)			
Single	25	50	25
Dual	31	19	69
Total	56	69	94
Plastic objects vs. metallic objects			
Single	31	31	25
Dual	6	13	19
Total	37	44	44

General Discussion

The results of the three experiments presented here suggest that infants are constrained in the kinds of structural part relations they will recognize in categorization. Infants between 14 and 18 months treated violations of part structure that did not affect the integral configuration of parts as equivalent to normal part structures. However, they did not treat violations that affected this configurational aspect of parts as equivalent to normal part structures. The structure of parts, and the relationship between the parts and the body of objects, may therefore act as 14- and 18-month-old infants' basis for categorization, though neither does so independently of the other. The results also reveal, however, that infants more readily separated objects with different parts (i.e., legs and wheels) than objects with matching parts (i.e., all objects with legs). This suggests that the role of parts within the structure of objects may be in some way primary to infants' categorization. Finally, the results show that textural cues do not play a role in 1- to 2-year-olds' categorization of animals and vehicles.

In general, these findings are in accord with those of Tversky (1989), who discovered that 5-year-olds detected faster that parts were missing when the parts affected the organizational integrity or canonical contour of the host object than when they were parts that did not. Tversky concluded that "children are sensitive to parts of common objects, particularly larger parts and those on canonical contours," and "they appear to be able to use this information in grouping objects into abstract, function-based superordinate categories" (p. 993). The results of the studies also confirm the conclusions of Landau and her colleagues (e.g., Landau, Smith, & Jones, 1992), who suggested that young children's bias for objects with the same shape "must engage object representations that admit of flexibility in the face of varying rigidity and changing part structure" (Landau, 1996, p. 349).

The dependence on the perceptible attributes of objects implies, in contrast to the view of Mandler and her colleagues

(Mandler, 1992; Mandler et al., 1991; Mandler & McDonough, 1993), that infants under 22 months may not categorize objects on the basis of one or more abstract image schemas or conceptual primitives. Infants are able to form superordinate-like categories without knowledge about the "kinds of things" objects are (Mandler & McDonough, 1993), and they may do so by relying on one or possibly more perceptible attributes. Hence, a reassessment of previous studies on infants' taxonomic categorization and a redefinition of the terminology used to describe it may well be warranted. This conclusion supports the view of Quinn and his associates (e.g., Behl-Chadha et al., 1995; Eimas & Quinn, 1994; Quinn & Eimas, 1996b), who argued that a change from an analogue perceptual code to an abstract image schema, as proposed by Mandler, is unnecessary. They claimed instead, as is posited here, that perceptual features are sufficient to categorize at the superordinate or global level, and the continual addition of perceptual information comes to define what is thought of as conceptual knowledge.

The finding that 14- and 18-month-old infants have a different basis for categorization from those at 22 months of age supports the results of previous studies that examined early taxonomic grouping. For example, across a number of different categorization tasks with various superordinate domains, Rakison and Butterworth (1998) found that 14- and 18-month-olds respond to objects primarily on the basis of parts, whereas 22-month-olds rely on additional, as yet unknown, properties. It is not clear what might account for the difference in performance between infants at 18 and 22 months. It has been shown that improved categorization tends to be accompanied by a rapid advance in language acquisition (Gopnik & Meltzoff, 1987, 1992; though see Gershkoff-Stowe, Thal, Smith, & Namy, 1997). However, it is ambiguous whether there is a causal relationship between the two developments or, indeed, whether advances in categorization might drive language development.

An alternative proposal by Rakison (1996, 1998), which is expanded on here, is that in the second year of life infants develop certain expectations about objects and their parts. According to Rakison (1996), it is these expectations that allow infants to advance beyond similarity judgments of perceptual features in category membership decisions. It is argued that different parts and part structures are correlated with properties that are classically thought of as nonobvious or conceptual. For example, in the case of locomotion, objects with legs tend to walk and jump, objects with wheels tend to roll, and objects with wings tend to fly. It is posited that infants are sensitive to these correlations and come to expect objects with certain object parts—maybe those parts that themselves move and are large (see Tversky, 1989)—to exhibit, or be capable of, particular kinds of movement. This claim is compatible with the findings of a recent study by Rakison and Cohen (1998) that used the sequential touching paradigm to test the role of functional parts in 14–22-month-olds' categorization. Infants were presented with tasks comprising both normal cars and cows or modified cars and cows. The results showed that 14- and 18-month-old infants made significantly more functional responses to objects with functional parts (e.g., "jumping" a cow with legs) than to objects without functional parts. By 22 months, infants made an equivalent number of functional responses to objects with and without parts. In addition, all three age groups were more likely to make functional responses on the basis of parts than on the basis of bodies, heads, or facial features; that is, infants "jumped" cars with legs and "rolled" cows with wheels.

Mandler (1992, 1993) and Lakoff (1987), among others, have suggested that fairly early in life, infants acquire knowledge about aspects of movement that goes beyond what is given in the perceptual input. However, Mandler's and Lakoff's theories are based on the notion that perceptual information is abstracted into conceptual image schemas that represent, for example, the movements of objects, causality, support, and so on. The position presented here does not make such inferences about the nature of infants' initial representations. Rather, it is argued that infants notice the co-occurrence of static and dynamic perceptual cues and it is this correlation that helps to define category membership. To expand on the example given earlier, many objects with legs (i.e., animals) are often seen to self-start, possess gait, and move nonlinearly, whereas many objects with wheels (i.e., vehicles) are often seen not to be self-starting and to move linearly. It is not necessary to posit that infants require an advanced conceptual system to abstract these kinds of properties from the perceptual array. Rather, infants need notice only the co-occurrences of object parts and particular actions or behaviors, and it is through these co-occurrences that they develop knowledge—initially in the form of certain expectations—of properties that are classically thought of as conceptual (e.g., animate motion).

The notion that processing biases and expectations may drive infant categorization and object perception is not entirely speculative. For instance, constraints on processing analogous to those found here have been previously demonstrated as present between 10 and 18 months of age in studies on the relationship between form and function. Madole et al. (1993) used object-examination tasks to examine 10-, 14-, and 18-month-olds' attention to form and function correlates. They found that 10-month-olds attend to form, 14-month-olds attend to form and function independently, and 18-month-olds attend to the relation between form and function; that is, by 18 months infants expected objects of one shape to roll and objects of a different shape to rattle. A more recent study by Madole and Cohen (1995) showed that 18-month-olds, but not 14-month-olds, attend only to form–function relations that do not violate the correlations found in real objects. Madole and Cohen surmised that 18-month-olds have developed constraints on the kinds of form–function correlates to which they will attend. They therefore concluded that

> there seems to be a developmental change in the particular kinds of features which serve as the basic elements to be categorized. . . . Initially these units may be only simple, structural features; later correlations among these simple features may become the basic elements; and later still correlations between function properties and structural features become the basic unit of processing. (Madole & Cohen, 1995, p. 645)

It remains to be seen, given the relative lack of empirical data, whether this is an accurate depiction of the developmental process underlying categorization. However, the study presented here, in conjunction with recent work on infant categorization, suggests that infants do attend to single features, the structure of features, correlations among features, and functional properties of features (e.g., Madole & Cohen, 1995; Madole et al., 1993; Quinn & Eimas, 1996a; Rakison & Butterworth, 1998; Younger & Cohen, 1986; Younger 1985, 1993). More important, perhaps, these works highlight the current trend away from an approach to early categorization that focuses on what the infant is capable of and toward a framework that has at its core the bases underlying behavior and the processes involved. It must be borne in mind, however, that the conclusions drawn here are based on infants' behavior toward toy animals and toy vehicles rather than toward their real-world counterparts. Elsewhere (e.g., Mandler, 1993; Rakison & Butterworth, 1998), it has been argued that infants, at least by 22 months, display behavior that suggests that toys are perceived as representations of real objects; for example, saying "hello doggy" or making cows "eat" plants. Further research is necessary to determine whether infants' categorical response to toys, and in particular modified toys, differs significantly from their response to those objects encountered outside the experimental setting.

In conclusion, the data presented here demonstrated that 14–22-month-old infants are sensitive to the structure of objects given by parts and attend to this information in categorization. These findings support the notion that there is a perceptual basis for early categorization. Infants will form superordinate-like categories on the basis of a single attribute, though it is not the attribute per se to which they attend. Rather, infants use structural features of objects to make category membership decisions, and large functional parts tend to have a significant effect on this aspect of objects. It is suggested that infants need not possess knowledge or beliefs about the origins and causes of category membership or about the nonobvious properties of objects. As an alternative, it is proposed that attention to large, moving parts such as legs and wheels may lead infants to notice the correlation between those parts and their function and movement. The evidence presented here and elsewhere (e.g., Behl-Chadha, 1996; Madole et al., 1993; Rakison & Butterworth, 1998; Tversky, 1989) supports such a theory and suggests that all that is needed by the infant to develop knowledge about the various properties of objects is readily available in the perceptual input.

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