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Shape: A Developmental Product

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Abstract

What defines sameness in shape? A precise definition has proved elusive despite considerable theoretical and empirical efforts across several disciplines. This chapter considers the idea that the perception of object shape—perceptions of the kind that can yield rapid and reliable object recognition—is learned by young children through their actions on objects and as a product of category learning. Action-based categories create shape caricatures, abstractions, that enable the systematic broadening of recognition beyond specific experiences. Thus the processes that yield facile and reliable object recognition may not be pre-specified in the visual system but rather may be experience dependent.

Functional feature

An abstraction, created in development, the consequence of category learning.

16.1 Introduction

Shape is crucial to object recognition and categorization. Objects labeled by the same common noun are typically similar in shape (Rosch, 1976); adults readily recognize objects from simple line drawings of their global shape (Biederman, 1987); and when asked to introspect on object categories, adults say that shape is a defining property (Samuelson and Smith, 1999; Rosch, 1976). Moreover, even two year olds appear biased to form object categories by sameness in shape (E. Clark, 1973*b*; Smith, 1999). These facts tell us that shape matters to human object recognition. But they do not tell us what shape is.

The theoretical definition of shape and its role in object recognition are heavily studied topics. Still, there is no accepted theory of shape similarity. The central premise of this chapter is that such a theory must be informed by the study of

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development because sameness in shape is a developmental construction, the product of early interactions with objects and early category learning. I pursue this idea in three steps. First, I present circumstantial evidence from the literature on children's early object categories. Second, I present new evidence that directly tests the idea that children learn to perceive abstract shape similarities by learning common object categories and by acting on objects. Finally, I consider the relation of these developmental findings to contemporary theories of object recognition. It is commonplace to think of perception as the bedrock on which categories are built. This idea is being increasingly challenged by studies showing category learning changes and close-up perception (e.g. Goldstone and Steyvers, 2001; Goldstone, Lippa, and Shiffrin, 2001; Schyns, Goldstone, and Thilbaut, 1998), and it is also challenged here by the finding that children's learning of common categories changes their perception of shape.

16.2 Some Circumstantial Evidence

16.2.1 Shape bias in early naming

Children say their first words at around 12 months and in the early stages of object name learning, they make many mistakes. Reports of these errors include labeling twirling lights as 'helicopter', calling all vehicles from bikes to planes 'car', calling oranges, fingernails, and plates 'moon', or calling swans and robins 'duck' (H. Clark, 1973; Macnamara, 1982; Mervis, 1987; Mervis, Mervis, Johnson, and Bertrand, 1992). From these examples, shape does not appear to be the sole nor necessarily the most compelling similarity driving early overgeneralizations.

However, the character of naming errors may change as children approach their second birthday, becoming more shape-based (see H. Clark, 1973; Gelman, Croft, Panfrang, Clauser, and Gottfried, 1998). In a recent study, Samuelson and Smith (2002) documented the potency of shape in two year olds' naming in a task designed to elicit overgeneralizations. They presented children with nonsense objects of various shapes, colors, and textures as shown in Fig. 16.1. The objects were not named for the children nor were the children asked to name the objects. However, as listed in Fig. 16.1, the children often did offer names for these things and for the most part, these names appear to have been guided by global similarities in shape. Samuelson and Smith (1999) confirmed the role of shape by asking adults to match the objects to the names offered by children. Adults could do so accurately when given information about only object shape but not when given information about only object color or texture. In sum, by about two years of age, but perhaps not before, shape similarity drives children's use of English object names.

Children's performances in laboratory tasks also suggest the progressive tuning of attention to object shape. One widely used task is artificial noun

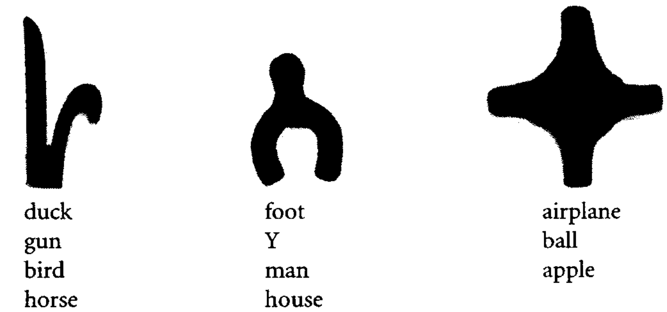

FIG. 16.1. Sample stimulus objects and names spontaneously offered as labels by two year olds in the Samuelson and Smith (2002) study.

learning. In these tasks children are presented with a novel object and it is named with a novel name. Then the experimenter asks what other things have the same name. Findings using this task suggest a developmental progression from linking the name to one particular thing, to generalization of that name to highly similar things, to the broad generalization of the name to a wide variety of things of similar shape. Woodward, Markman, and Fitzsimmons (1994) provide the evidence for an early broadening of generalization between 13 and 18 months. They found that 13 month olds would generalize a name to an object identical to the originally named thing but these young children were much less likely to extend the name to objects that differed even slightly from the original. In contrast, 18 month olds consistently generalized the name to new instances that were non-identical but highly similar overall. Thus, generalization of a just heard name broadens between 13 and 18 months. By the time children are two years old, category extensions expand even further to include objects the same shape as the original exemplar no matter how much they differ in other properties. For example, Landau, Smith, and Jones (1988) found that two and three year old children generalized a novel object name to all new instances with the same shape as the originally named exemplar; they did so even when the test items were 100 times the size of the original and even when they differed radically in textural and material properties from the originally named exemplar (e.g. wood versus sponge or chicken wire). By two years of age, shape dominates children's categorization of novel objects.

This developmental progression toward shape-based categories occurs at the same time that children's productive vocabularies rapidly expand. Thirteen month olds acquire new object names slowly and use the names they know often only in narrow contexts and with respect to only certain objects (e.g. Mervis, 1987; Woodward, Markman, and Fitzsimmons, 1994). They need repeated experiences with multiple exemplars to determine the full range of category members. By the time children are two years old, however, new object name acquisitions accelerate rapidly to a pace of about three or four new object names *a day* (see, Bloom, 2000 for a review). At this point in development, children often need to hear only a single object named to then use that name correctly across the entire range of the category. Smith (1999; Smith *et al.*, 2002) has suggested that this acceleration is due, at least in part, to children's increased attention to shape and moreover that this increased attention to shape is learned, the product of learning object names during the early slow course of word learning (see Smith *et al.*, 2002).

16.2.2 Symbolic play and the functions of things

During this same developmental period, there are also changes in how children play with objects. As early as 12 months of age, infants show that they recognize object categories by their actions on them—making drinking sounds when playing with an empty cup or using a doll's brush on their own hair (Belsky and Most, 1981). A little later, children direct these actions towards pretend objects—giving a doll a drink from a cup, or brushing a teddy bear's fur. These kinds of activities are called pretend play; children perform characteristic actions on clear instances of well-known categories. Between 18 and 24 months, children add a new and more creative kind of play, called symbolic play, to their repertoire. Here children use objects, often of simple shapes, as stand-ins for the real thing. For example, they might use a banana as a phone, a shoe box as a bed, or a stick as a bottle (see, McCune-Nicolich, 1981*b* for a review). Symbolic play is a signal developmental achievement. It correlates tightly with early vocabulary growth (Corrigan, 1982; Shore, O'Connell, and Bates, 1984; Veneziano, 1981) and is a well-established marker of normal language development. Children who do not engage in symbolic play exhibit significant delays in language acquisition (e.g. McCune-Nicholich, 1981*b*).

No one has previously suggested a link between symbolic play and attention to shape. However, as illustrated in Fig. 16.2, the substitutions reported in the literature suggest that these are shape-based extensions. At the very least, children must be able to perceive the global shape similarity of a banana to a phone and of a box to a bed, if they are to make these kinds of inventive substitutions in play. Importantly, play itself and the actions afforded by object shape may also guide children's perception of shape similarity. Dolls can be placed in beds *and* in boxes and the action of placing may highlight the functionally critical aspect of the shapes of beds and boxes when they serve as beds. Analogously, a phone *and* a banana can be held in similar ways, and holding each so that one end touches an ear and the other the mouth may highlight a particular aspect of shape similarity. Thus, it seems possible that acting on objects, using them in some functional task, may educate children about object shape. Despite an extensive literature on the roles of function and shape in children's categorization, there have been no

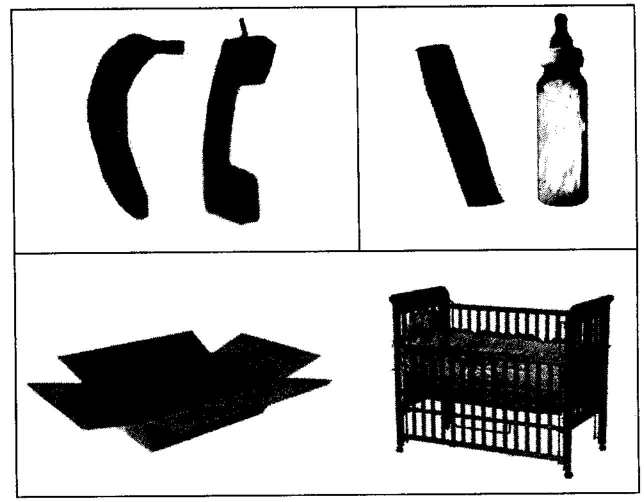

FIG. 16.2. Real objects and the simple forms used by children as substitutes for those things in play.

studies of how action may alter the perception of shape. This is because the issue has been cast in terms of a dichotomy between perceptual (e.g. shape-based) versus conceptual (e.g. function-based) categories (e.g. Smith, Jones, and Landau, 1998; Landau, Smith, and Jones, 1996; Kemler Nelson, 1999). Specifically, empirical studies have pitted shape against function and sought to show either that children form categories by shape unaffected by functional information or form categories by function unaffected by shape and perceptual similarity. There are long lists of experiments on both sides of the issue (e.g. Gathercole, Mueller, and Whitfield, 2001; Graham, Williams, and Huber, 1993; Merriman, Scott, and Marazita, 1993; Kemler Nelson, 1999; Smith *et al.*, 1996; Landau *et al.*, 1996). Because these experiments pit how we act on (and use) objects against shape, they provide little insight into the question of whether actions *alter* perceived shape.

However, one series of studies by Kemler Nelson and colleagues (1995; 1999; Kemler Nelson *et al.*, 2000) suggests a possible role for action in defining shape similarities. In one study (Kemler Nelson *et al.*, 2000), two year old children were presented with novel complex objects with multiple parts like those shown in Fig. 16.3. One object, the exemplar, was named with a novel name. In addition, the children were shown a function that depended on one of the parts, for example they were shown how the hinged shape could open, close, and latch. After seeing and manipulating the hinge, the children were more likely to extend the object name to the test objects that also had hinged parts rather than to those that were similar in global shape but lacked the hinge. By Kemler Nelson's interpretation, the children formed conceptually-based functional categories rather

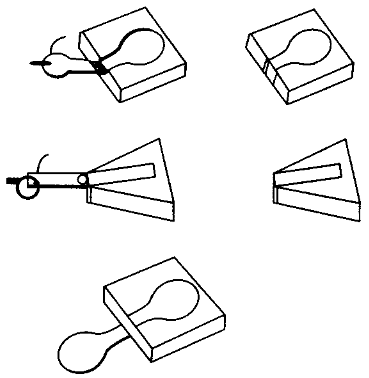

FIG. 16.3. Illustrations of the objects used by Kemler Nelson *et al.* (2001): the exemplar in its closed and open form and the 'function' matching test object that closes and opens and the 'shape' matching object that does not close.

than shape-based perceptual categories. However, by another interpretation, the actions children performed on the objects may have changed how object shape was perceived. That is, perception itself may be molded by top-down experiences and may not be separable from them (see, Goldstone and Barsalou, 1998).

16.3 New Evidence on Developmental Changes in the Perception of Shape Similarity

The developmental period between 18 months and two years is a momentous one characterized by a rate increase in early object name learning and in the emergence of symbolic play. It may also be a period that is foundational to the definition of shape and shape similarity. The following three hypotheses serve as starting points for pursuing this idea.

Hypothesis 1. Perceived similarities in shape become more abstract as children learn more object categories. As adults, we think of chairs as all having the same shape but all the things we call 'chair' are not exactly the same shape. Kitchen chairs, stuffed chairs, and rocking chairs are similar in shape only under some highly abstract description of shape. When do children have access to these abstract descriptions? One possibility is that children may develop more abstract representations of object shape as they acquire object names. Category learning may blend the specific shapes of specific things to create shape 'caricatures' that preserve the psychologically essential properties of shape.

Hypothesis 2. These shape abstractions broaden the range of objects included in the functional class. Children's object substitutions in symbolic play suggest that they do perceive abstract similarities in shape, ones that encompass the shared shape similarity of shoe boxes and beds, of bananas and phones, and of sticks and bottles. Symbolic play may be a signal developmental achievement precisely because it indicates a perceptual achievement, abstract representations of shape that highlight functionally relevant properties.

Hypothesis 3. Actions on objects directly influence how the shapes of those things are perceived. Just as perceived shape may invite actions, actions may alter perceived shape. If this is so, category learning, action, and perceived shape would form a self-organizing system, each training the other, driving the system toward more abstract, more category relevant, and more functionally appropriate representations of shape.

16.3.1 Experiment 1: recognizing shape caricatures

Figure 16.4 shows pairs of objects: one a simple but recognizable caricature and the other a richly detailed and lifelike form. Can children recognize the category from the minimal shape information provided by the caricature? Does the ability to do so increase as children acquire more extensive knowledge of common object categories? Is recognition of shape caricatures evident in both children's naming and in the actions they perform on objects?

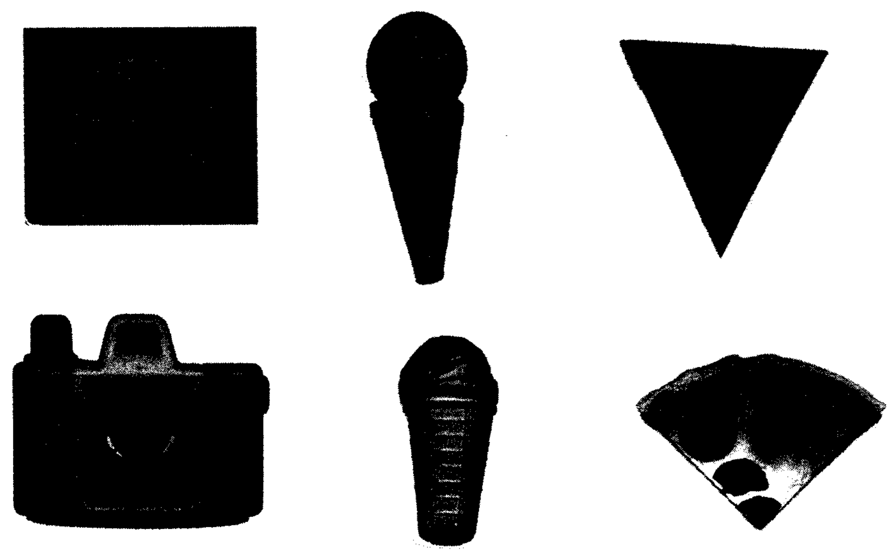

FIG. 16.4. Three-dimensional shape caricatures of common objects and their corresponding lifelike examples.

To answer these questions, Smith (2003) presented Lifelike and Caricature objects were presented to 26 children between 18 and 24 months of age in two tasks: a Play task and a Name comprehension task. The children were divided into two equal groups, those with less than 100 object names in their productive vocabulary and those with more than 100 names in productive vocabulary. The number of object names in productive vocabulary is used as a measure of children's expertise with respect to common object categories. Productive vocabulary was measured by parent report using the MacArthur Communicative Developmental Inventory (Fenson *et al.*, 1994). This is a vocabulary checklist that includes the 300 object names commonly learned first by children learning English.

Lifelike and caricatures versions of 16 common categories were used: cat, chair, pizza, hammer, camera, lollipop, banana, phone, basket, hammer, boat, ice cream, toothbrush, apple, and butterfly. The Life-like instances were all prototypical toy replicas, rich in color, shape, and textural detail. The Shape Caricatures were three-dimensional forms carved from styrofoam and painted a uniform grey. These presented minimal shape detail but were recognizable to adults in a pilot study (see also Biederman, 1987). The three pairs in Fig. 16.4 are photographs of three-dimensional stimuli used in the experiment.

On each trial of the play task, three randomly selected objects were set on the table for one minute and the child was encouraged to play with the objects. None of the objects were named. A child was credited with recognizing an object as a member of the target category if the child performed a category specific action with the object. For example, a child was credited with recognizing an object as a phone if the child pretended to dial a number and/or answer or talk on the object. On each trial of the Name comprehension task, the child was presented with three alternatives and asked to indicate one object by name: For example, 'Where is the phone? Show me the phone'. Each child was tested in both the Play and Name comprehension tasks and the Play task for each object always occurred prior to the Name Comprehension task. Each child was tested with Life-like and Caricature objects in a counterbalanced order. However, no child ever saw both the Lifelike and Caricature version of the same object.

The results suggest that recognition of shape caricatures increases with increasing knowledge of common object categories. The evidence from the Play task is shown in Fig. 16.5. As can be seen, children with fewer than 100 object names and children with more than 100 object names played with the Lifelike objects in category specific ways. For example, they pretended to answer the phone, they made the cat meow and walk, they pretended to lick the ice-cream cone. Thus, both groups of children recognized richly detailed examples of these categories and knew how they are commonly used. However, only children with more extensive category knowledge (as measured by known object names) played with shape caricatures in category specific ways. The children with more extensive object name vocabularies pretended to take pictures with the realistic camera and the

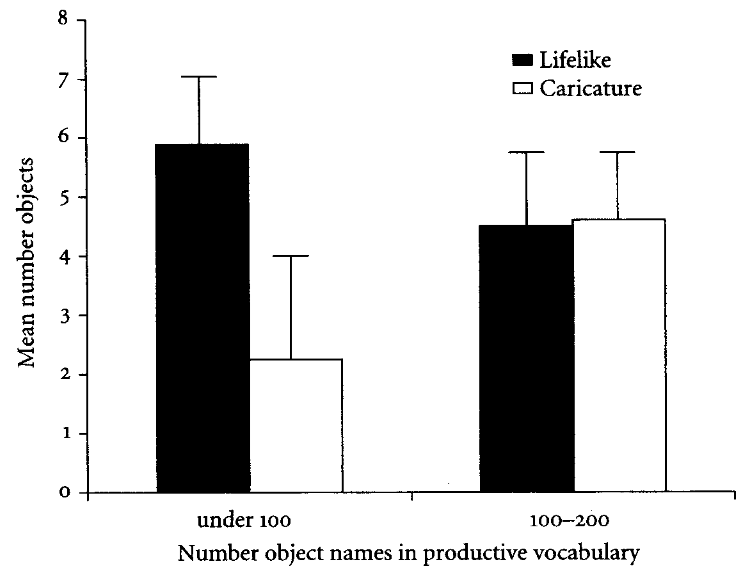

FIG. 16.5. Mean number of objects (maximum eight) that children played with in category specific ways for children with fewer than 100 object names in their productive vocabulary and for children with more than 100 object names in their productive vocabulary.

shape caricature, they pretended to eat the realistic slice of (plastic) pizza and the caricature slice, and so on. For these children, the minimalist shape information in the caricatures was sufficient to elicit actions characteristic of the kind. The children with less extensive vocabularies did play with the caricatures, just not in category specific ways. Figure 16.6 shows children's total actions—of all kinds—on the objects during the Play task. Children in both vocabulary groups manipulated the Lifelike and Caricature objects equally often, for example, by touching them, rolling them, showing them to the experimenter, or using them in play. In sum, the two groups of children differ only in their category specific actions on the Shape Caricatures. This result suggests that during the course of early object name learning, children form abstractions of the shapes of common things, and moreover that these abstracted shapes are linked to functional and category specific actions.

This link between abstract shape recognition and action suggests a new explanation of the emergence of symbolic play. Children's category specific play with the Shape Caricatures is like symbolic play in that the objects are not real instances of the categories; indeed they are very much like the simple forms used in studies of symbolic play (Shore *et al.*, 1984). Consistent with previous research, the present results show a strong link between this kind of play and early vocabulary development. The children who extend category specific actions to objects roughly similar in shape—but perhaps similar along the most category

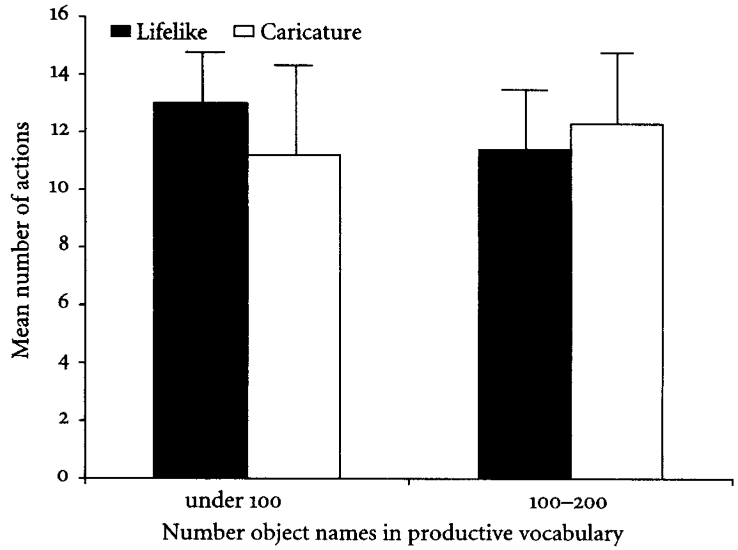

FIG. 16.6. Total number of actions (both nonspecific and category specific) for children with fewer than 100 object names in their productive vocabulary and for children with more than 100 object names in their productive vocabulary.

relevant aspects of shape—are the ones with more developed language. These results suggest further that the link between symbolic play and early vocabulary development may be through the perception of shape, that symbolic play emerges as children begin to form abstract descriptions of object shape and thus can extract the relevant shape similarities across different kinds.

The pattern of results in the Name comprehension task is very much like that in Play task. As shown in Fig. 16.7, children with smaller noun vocabularies recognized the Lifelike objects, selecting the right one 70 percent of the time, but they failed to recognize the Shape Caricatures. In marked contrast, however, the children with larger noun vocabularies recognized both the Lifelike objects and the Caricatures, selecting the named object over 75 percent of the time both for the Lifelike objects and the Shape Caricatures. Thus children with less extensive object name vocabularies appear to need more detail to recognize an object than do children will more extensive object vocabularies who seem to need only a rough caricature of object shape.

These results provide three new insights into the developmental origins of shape. First, young children in the early stages of category learning do not recognize shape caricatures at all, despite their accuracy in recognizing richly detailed instances of the same category. Apparently, the ability to perceive abstract shape similarities is not a given but is instead a developmental product. Second, very young children who are only slightly more advanced in their category knowledge recognize these

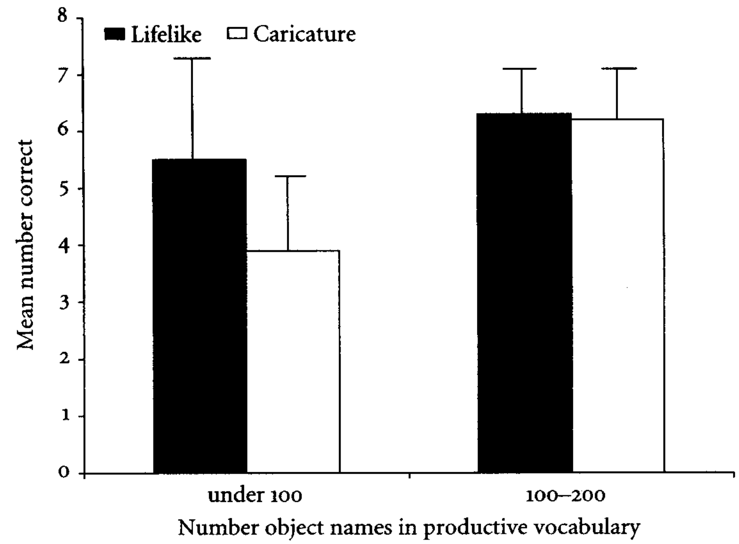

FIG. 16.7. Mean number correct in the Comprehension task for children with fewer than 100 and more than 100 object names in their productive vocabulary.

caricatures of known categories nearly perfectly, that is, as well as they recognize richly detailed instances. Clearly, the processes of object recognition change during this developmental period. Third, there is a link between children's perception of shape and category specific actions. Recognition of shape caricatures may a crucial step in extending actions, in enabling, for example, children to see how a shoe box can stand in for a bed. In this way, developmental changes in the perception of shape may be a key ingredient in the development of symbolic play.

These results also raise new empirical questions. First, the results indicate a strong link between children's knowledge of object names and their recognition of shape caricatures. But they do not tell us the causal direction of that relation—whether the ability to recognize shape caricatures drives category leaning (and object name acquisitions) or whether category learning creates the ability to recognize abstract shapes. The results also do not tell us the nature of the developmental change nor the specific experiences that might drive it. One possibility is that children learn to recognize shape caricatures, category by category. Alternatively, the developmental changes may be more general, changing how children perceive shape similarities for novel as well as known objects. This question was addressed in a second experiment.

16.3.2 Experiment 2: recognizing novel shape caricatures

In a second experiment, 18–24 month old children were introduced to a lifelike but (for young children) novel object, for example, an artichoke. The children

FIG. 16.8. Photographs of a realistic artichoke and a caricature of an artichoke.

were taught the object's name, for example, they were repeatedly told that the object was 'an artichoke' and were trained to select the artichoke from among distractors. On the critical test trial, three shape caricatures were presented to the child, one of which was a shape caricature of the originally named exemplar as shown in Fig. 16.8. The child was asked to indicate the named object, for example, 'Where's the artichoke here?' Children were tested on eight novel objects in this manner. If children must master the relevant shape properties category by category, then this task should be very hard because the caricatured artichoke only preserves some aspects of the original shape. If, however, children are developing general perceptual skills that apply to novel shapes, then children who recognize the caricatures of familiar objects might also recognize the caricatures of novel ones. The results support this second possibility. As shown in Fig. 16.9, children with more than 100 object names in their productive vocabulary (those who readily recognized caricatures of familiar object shapes in Experiment 1) readily recognized the caricature of the newly learned noun. Children with fewer than 100 object names did not. These results strongly suggest that children are learning something general about the shape similarities relevant to object recognition and categorization.

16.3.3 Experiments 3 and 4: Action helps create perceived shape

The third hypothesis states that actions on objects also influence how the shapes of those objects are perceived. A thought experiment illustrates both the idea and the experimental task used to test it. Consider the object in the top of Fig. 16.10. Imagine that you characteristically act on this object by lifting it vertically. Now, consider the objects at the bottom. Which of these belongs to the same category as the original exemplar? The conjecture is that you are more likely to categorize the exemplar with the vertically rather than the horizontally elongated alternative

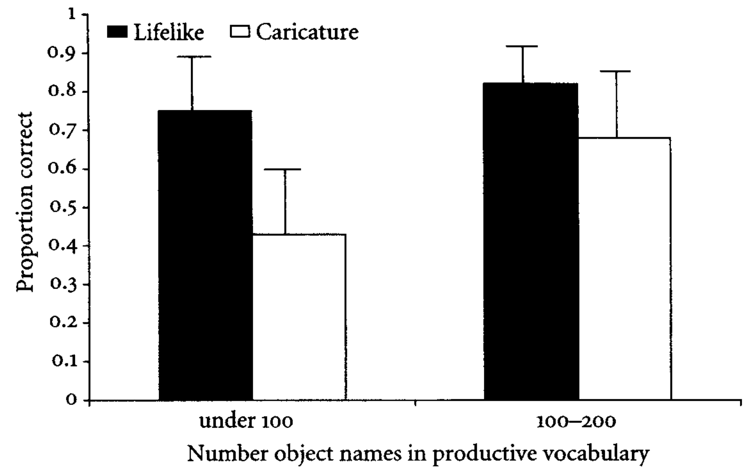

FIG. 16.9. Mean number of correct choices for children with fewer than 100 and more than 100 object names in their productive vocabulary.

because you moved the object vertically. The conjecture appears to be right, at least for two-and-a-half and three year olds.

In the experiment, 25 children were presented with the exemplar object in the figure and told its name, 'This is a zup.' Thirteen of the children were then shown the object moving vertically and were also given the object so that they could move it vertically along a backdrop. The remaining 12 children were shown the object moving horizontally and then actively moved the object horizontally along the backdrop. The backdrop was a 1 meter square with 'grass' along the bottom edge and a 'tree' along the right side. In the horizontal action condition, children moved the exemplar horizontally along the grass. In the vertical action condition, children moved the exemplar up and down the tree. After acting on the exemplar, it was set down and remained in view as the children were shown individual test objects. The children were asked whether each individual test object was also 'a zup'. There were six unique test objects as shown in Fig. 16.11. Test object H1 was horizontally elongated but differed moderately from the exemplar. Test object H2 was more horizontally elongated and thus differed considerably on this dimension from the exemplar. Test object −H differed from the exemplar only in that it was shortened along the horizontal dimension, thus this object was taller than it was wide. Test objects V1, V2, and −V were similarly constructed, only the changed dimension (relative to the exemplar) was the vertical dimension. The children were queried three times about each test object for a total of 18 trials. After every trial, children were given the exemplar and asked to reperform the action of moving it along the backdrop horizontally or vertically.

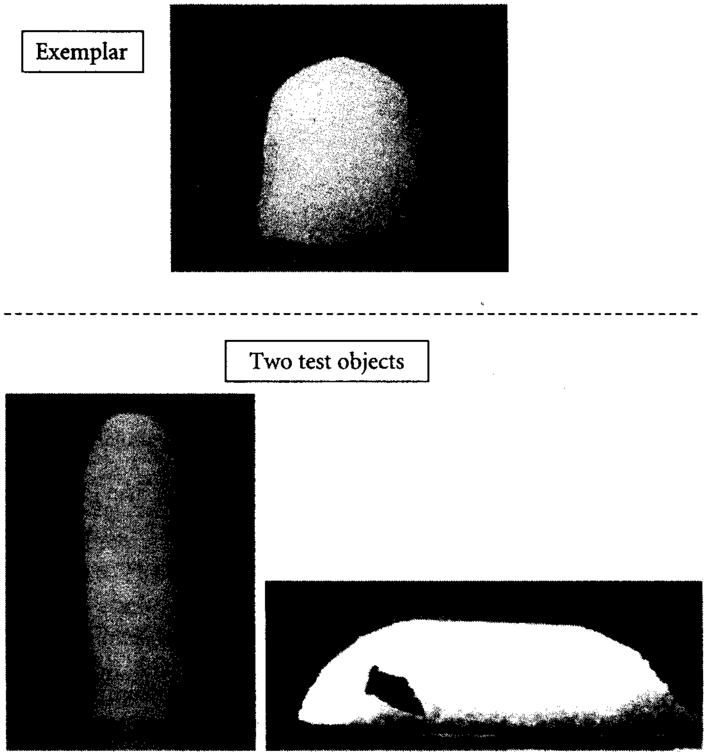

FIG. 16.10. The exemplar and two test objects.

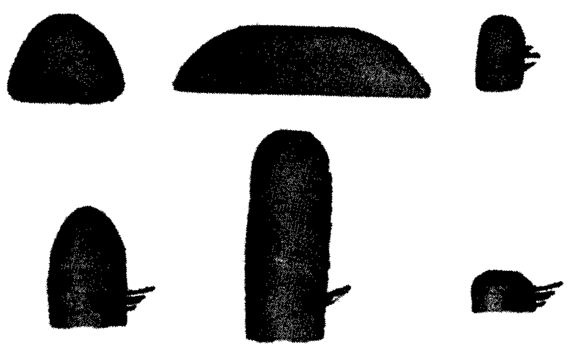

FIG. 16.11. Six test objects. Top row: horizontally extended (H1 and H2) and horizontally decreased (–H) relative to the exemplar (in Fig. 16.10). Bottom row: vertically extended (V1 and V2) and vertically decreased (–V) relative to the exemplar.

If the conjecture about the role of action in perceived shape is correct, then children who moved the exemplar in a horizontal fashion should perceive it as being more horizontally extended than vertically extended and thus should extend the name to test objects H1, H2, and –V more than they should extend the name to test objects V1, V2, and –H. The opposite pattern is expected for children in the vertical action condition.

The expected pattern was strongly present in the children's judgments. As shown in Fig. 16.12, when the children acted by moving the exemplar along a horizontal path, they generalized the name to test objects H1 and H2, the horizontally extended test objects, and also to test object –V, a test object that was also wider than it was tall. When children acted by moving the exemplar along a vertical path, they generalized the name to tests objects V1 and V2, the two vertically extended versions of the exemplar. They did not include test object –H in the category at levels reliably above chance. This evidence suggests that action plays a formative role in the perception of shape. How children use an object influences how they perceive its shape and the shape similarities that organize categories.

This conclusion is also supported by a second study that shows a role for action in the perception of symmetry. In this experiment, children between two-and-a-half and three years of age were shown the exemplar in Fig. 16.13 and told its name, for example, 'This is a zup.' They were also shown and asked to perform

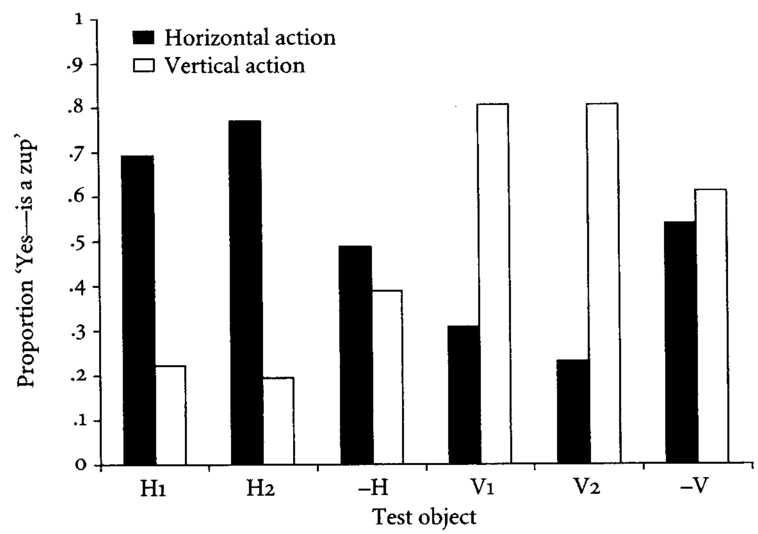

FIG. 16.12. Proportion name extensions to each of the six kinds of test objects for children in the Horizontal and Vertical action conditions.

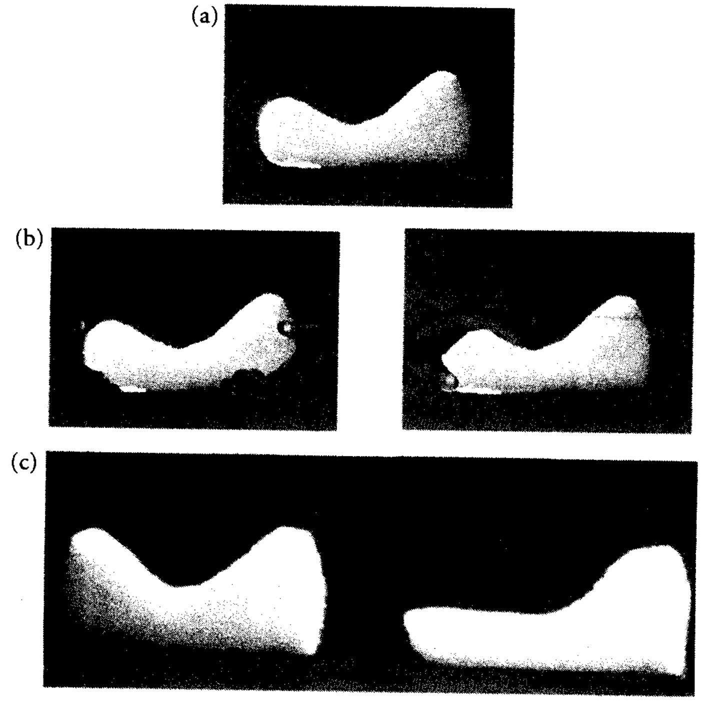

Fig. 16.13. (a): the exemplar. (b): the two kinds of actions—symmetrical and asymmetrical. (c): two of the test objects (S2 and A2).

an action with the object. Half the children were shown and asked to perform and action in which the object was held by its smaller side and waved, as illustrated in Fig. 16.13. Half the children were shown and then were asked to perform an action in which the object is held with two hands, one on each point and then rotated, also as shown in Fig. 16.13. The central question is this: Does asymmetrical action relative to an object's shape increase the likelihood that it is perceived as having an asymmetrical shape? Does symmetrical action increase the likelihood that the object is perceived as being more symmetrical in shape?

A novel noun extension task was again used to answer these questions. After learning the name and acting on the exemplar, the children were presented with individual test objects and asked about each of these 'Is this also a zup?' A series of test objects were constructed that were incrementally more or less symmetrical than the exemplar. Test objects A1, A2, and A3 are progressively more asymmetric and progressively more different than the exemplar. Test objects S1, S2, and S3 are progressively more symmetric and progressively more different from the exemplar. Children were asked about each test object four times (presented in

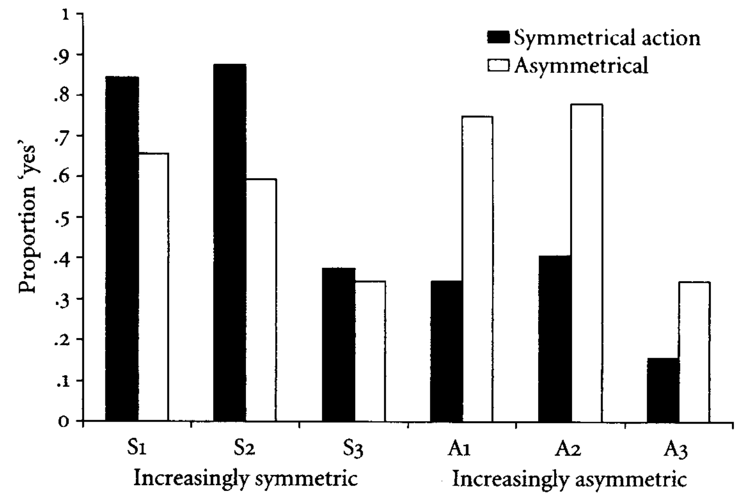

Fig. 16.14. Proportion names extensions to the six test objects for children in the symmetrical and asymmetrical conditions.

a random order) for a total of 24 trials. After every four trials the child was reshown the action on the exemplar and then given the opportunity to perform that action.

The results are shown in Fig. 16.14. Children who used one part of the exemplar as a handle, extended the name differently than those who had held and moved the object with two hands. Children in the first condition extended the name to new instances that were more asymmetric in their structure than the exemplar but children in the second condition extended the name to new instances that were more symmetric than the exemplar. As is apparent in the figure, magnitude of similarity also mattered, children accepted the smaller deviations toward or away from symmetry depending on condition but not the largest ones (A3 and S3). This similarity effect is consistent with the idea that the effect of action was on perception and not on children's inferences about the kind of object (symmetric or asymmetric) that was suitable for the motion. The action perturbed perceived similarity in the direction of symmetry or asymmetry but did not cause the child to accept shapes well-adapted to the action but dissimilar to the exemplar. In sum, the results suggest that how children act on objects influences how they perceive object shape and the range of allowable shape variation within a category.

The implication of these results is clear: How we use objects influences the aspects of shape children take to be relevant to categorization. These results also provide a means to unify the role of function and shape similarity. Perceived shape and function may not be psychologically separable because the perceived shapes of things determine actions and actions distort in functionally relevant ways perceived object shape.

16.4 Toward a Theory of Shape

These new results strongly indicate that a complete theory of shape will be a developmental theory. The first two experiments show that between the ages of 18 and 24 months, children's perception of shape similarity changes markedly. Children progress from generalizing both actions and names narrowly to a small set of richly similar objects to a broader category encompassing generalizations that seem to depend on an abstract, pared down representation of shape. Experiments 3 and 4 show that actions also influence children's perception of shape, distorting perceived shape in the direction of action.

Because the results are new, there are many empirical gaps, many unanswered questions. But the overall pattern of inter-related developments suggests a potentially powerful story about how and why we perceive object shape the way we do. Children may begin learning about objects by attending to all aspects of shape, those we consider merely decorative may attract attention as much as those that seem (to adults) as essential properties. Thus, to a novice learner the differences in the shape of the chairs in Fig. 16.15 may be just as potent as the similarities. However, as children encounter the full variety of chair shapes and as the child acts on these various chairs in the same way, by sitting, an abstract model of chair shape—one that transcends the specific shapes of specific things—may emerge. These shape models, in turn, will foster further category generalizations and actions, thus refining perceived shape and links to function even further. Thus object shape may be developmentally defined through a child's actions on objects and through category learning. The intriguing implication is that we would perceive the shapes of chairs differently if our culture placed chairs and stools in the same category, or if we used chairs to fight lions rather than to sit on.

FIG. 16.15. Three chairs of different specific shapes but the same general shape.

16.4.1 Theories of object recognition

Contemporary theories of object recognition are not developmentally grounded. They do not take infants and children as their starting point but instead start with the two-dimensional representation on the retina and ask how to build a three-dimensional object from that two-dimensional image. There are two competing classes of theories (e.g. Biederman, 1987; Tarr, 1995). According to Biederman's Recognition-by-Components (RBC) theory, objects are represented in terms of abstract components, generalized cylinders, called geons. These components are abstracted from the two-dimensional image independently of changes in orientation and scale. According to RBC, only a few such components in the proper spatial arrangement are needed to represent a recognizable object. By this account, then, the reason all sorts of chairs are seen as chair shaped is that they all conform to the same componential representation. The shape caricatures used in Experiments 1 and 2 share considerable similarity to the kinds of simplified objects that might be built from Biederman's geons. Although RBC makes no explicit developmental claims, the processes that parse images into componential object representations are typically discussed as unlearned and developmentally stable processes. Contrary to this idea, the present results suggest that the processes that underlie object shape are a developmental product.

Edelman and colleagues (1995, 1999; Edelman and Duvdevani-Bar, 1997) offer a different view of how shape is represented. They propose a theory of recognition and categorization that begins with the premise that perceivers store view-dependent images of objects. Prototypes are formed from multiple images of multiple objects in the same category. These prototypes are interpolated blends of stored images and thus represent simplified and global characteristics of shape. Duvdevani-Bar and Edelman (1999) argue further that once a number of such prototypes have been formed they serve as landmarks, as basis functions, defining the shape space and enabling the recognition of even novel categories. In this view then, early learned object categories *create* the dimensions by which object shape is perceived. The results of Experiments 1 and 2 may be interpreted as providing support for this account.

Neither Biederman nor Edelmann provides a means for connecting perceived shape to action. Both are firmly within Marr's (1982) modular view of vision as a device for deriving general purpose descriptions. This Marrian view contrasts with the Gibsonian (e.g. Gibson, 1987) perspective which sees perception tightly linked to the dynamics of action. Recently, there has been growing interest in the idea that both Marr and Gibson are right, but that each describes a distinct visual system. Goodale and Humphrey (1998) proposed separate but interactive visual systems—one Marrian that evolved to represent objects and one Gibsonian that evolved for the control of action. This idea was based in part on Mishkin, Ungerleider, and Machio's (1983) identitication of two distinct 'streams' of visual processing in the macaque monkey—a ventral stream heavily invested in object

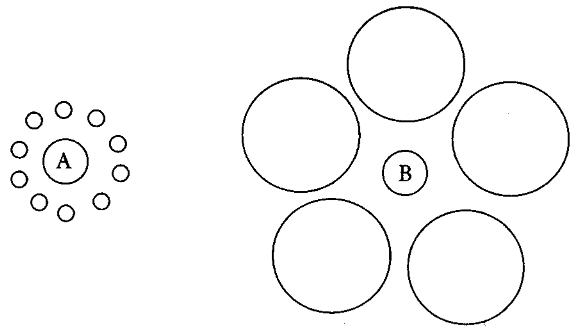

FIG. 16.16. Ebbinghaus Illusion.

recognition and a dorsal stream more heavily invested in spatial vision. Goodale and Humphrey (1998) review a number of results that support this divide between perceiving objects and acting on them.

One compelling result concerns the Ebbinghaus Illusion as illustrated in Fig. 16.16. The standard version of the illusion uses a two-dimensional drawing. The two center circles are the same physical size; however, circle A is surrounded by smaller circles and is perceived as larger and circle B, surrounded by larger circles, is perceived as smaller. Aglioti *et al.* (1995) developed a three-dimensional version of the illusion using poker chips. When viewing these chips in arrays like those in Fig. 16.16, participants still judged circle A to be larger than circle B. Participants were also asked to pick up the disks and their grip aperture was measured. The opening of the fingers during a reach and prior to contact with the object—grip aperture—is a highly sensitive and accurate measure of size. And it was in this case; participants' grip apertures were not affected by the size contrast illusion. These sorts of results suggest that the systems that represents object properties such as size and the action system do not influence each other.

However, this conclusion may be too simplistic. After all, action is driven by the object properties and knowledge of category membership. This appears to be true even when those properties or category membership is irrelevant to the task at hand (see Glenberg and Kaschak, this volume, Ch. 2). For example, Ellis and Tucker (2000) found that in a task in which sounds cue particular hand motions, an irrelevant object in the field perturbs the response in the direction of that appropriate to the object. Similarly, Creem and Proffitt (2001) found that movements toward an object are influenced by the characteristic (but not task relevant) functional use of the object. Finally, frontal lobe patients who are generally over-responsive to the environment also cannot prevent themselves from performing a familiar action with a familiar object (e.g. Lhermitte and Serdaru, 1993; Riddoch, Humphreys, and Edwards, 2000). These results all suggest that our actions are influenced by our representations of objects; and moreover, that our object representations include information about the actions associated with them.

The present results fit this idea in that they suggest that young children form these action-laden representations as they form early categories and as they form more abstract representations of object shape. Experiments 3 and 4 further suggest a direct influence of action on object representation. All the previous studies have shown that object shape (and function) influences action (even when the shape and function are irrelevant to the task). Experiments 3 and 4 show the opposite direction of influence—from action to the perception of shape. I believe this is the first such demonstration that how one uses an object determines its perceived shape. From these two experiments, one cannot make strong conclusions about the mechanisms responsible for this effect. It seems unlikely that movement in a particular way simply increases attention to some dimensions over others. Increased attention to a dimension typically leads to heightened sensitivity to differences on that dimension (e.g. Goldstone and Steyvers, 2001). Thus, if moving an object vertically led to increased attention to the vertical dimension, one would expect increased sensitivity to differences on the vertical dimension. But Experiment 3 indicates the opposite result: the children showed an increased willingness to extend the category to vertically elongated objects.

Rather than increased sensitivity, the results of Experiments 3 and 4 suggest a blurring or blending of the object representation with the action. Memory for the vertical extent of the action, or memory for symmetry of the action, seems to be confused with or combined with the perceived extent or perceived symmetry. Critically, from the current experiments, we cannot tell if it is a combination of perceived action with perceived extent (or symmetry) or whether it is a combination of the felt pattern of body motion with the perceptual properties of the objects. Experiments are underway to address this issue.

16.4.2 Conclusion

Shape similarity develops. It is not a given upon which category formation rests but is, at least partially, a product of category learning—of learning what things are called by the same name and of learning the functional uses of objects. As children's knowledge of common object categories expands, narrow recognition of only richly detailed instances gives way to the recognition of stylized forms for well-known categories and to an increased recognition of abstract shape similarities within novel categories. Shape itself appears to be an abstraction, created in development, the consequence of learning functional categories.