Shape and the First Hundred Nouns

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This paper reports evidence from a longitudinal study in which children's attention to shape in a laboratory task of artificial noun learning was correlated with a rate shift in noun acquisitions. Eight children were tested in the laboratory at 3-week intervals beginning when they had less than 25 nouns in their productive vocabulary (*M* age = 17 months). Children were presented with a novel word generalization task at each session. Additionally, the study examined the kinds of words the children learned early, based on parent reports, and the statistical regularities inherent in those vocabularies. The results indicate that as children learned nouns, they also learned to attend to shape in the novel word task. At the same time, children showed an acceleration in new noun production outside of the laboratory.

Shape is a feature that human infants appear ready to notice (Johnson, 2001; Spelke, 1990). Attention to shape is essential to the everyday recognition of objects (Biederman, 1987; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976) and to the nouns that dominate the speech young children hear (Poulin-Dubois, Graham, & Sippola, 1995; Sandhofer, Smith, & Luo, 2000). Much research has been devoted to establishing the importance of shape to successful noun learning. In studies that examine children's understanding of how nouns link to object categories, investigators have found a general tendency to extend novel names to solid things that share a common shape (Baldwin, 1989, 1992; Imai, Gentner, & Uchida, 1994; Jones, Smith, & Landau, 1991; Landau, Smith, & Jones, 1988; Samuelson & Smith, 1999; Smith, Jones, & Landau, 1992; Soja, Carey, & Spelke, 1991).

Although the existence of a shape bias is not controversial, the question of how pervasive it is, what its relation is to children's conceptual knowledge, and whether it is the product of more bottom-up or top-down processing has generated much controversy (e.g., see Diesendruck & Bloom, 2003; Gelman & Koenig, 2003). Most have agreed, however, that children commonly extend the name of an object to new instances by shape and that this be-havior serves as a good index of their early word learning.

In its most advanced form the shape bias is observed when children are presented with totally novel objects (indeed, nonce objects) named with novel names. The fact that the shape bias is evident with entirely novel things suggests that it may play an important role in lexical learning as a heuristic that enables children to attend to a category-relevant property even when they have no other knowledge about the category. If this is so, one might expect attention to shape to be a causative force in the rate of new noun acquisitions. One problem with this hypothesis is that the most robust form of the shape bias (i.e., in generalizing novel names for novel things by shape) emerges after children have already learned many nouns (more than 150; Landau et al., 1988; Samuelson & Smith, 1999; Smith, 1995). The purpose of this study was to reexamine the relation between a shape bias in novel name generalization and early noun learning. We did so through a longitudinal study in which we tracked children's acquisition of their first 100 nouns, the first emergence of a shape bias in novel noun generalization, and the rate of new noun acquisitions. This reexamination appears warranted in light of the conflicting evidence on the role of shape in children's early categorizations and in light of new evidence suggesting that attention to shape may facilitate new noun acquisitions (Samuelson, 2002; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002).

An Early Emerging Shape Bias?

There are studies that suggest a very early link between naming and categorization and studies that

suggest that children use properties other than object shape when first categorizing. For example, in one important study, Waxman and Markow (1995) examined 12-month-old infants' ability to form categories in a familiarization paradigm. They presented infants with instances of the category animal (e.g., bear, duck, lion, and dog) during a familiarization phase and with novel within- or out-of-category instances during the test phase (e.g., cat vs. apple). A novelty preference for the out-of-category instance was interpreted as evidence of categorization. The central result was that infants showed this novelty preference only when the original instances had been named during familiarization, a result that suggests that naming helps direct attention to category-relevant properties and does so long before the shape bias emerges in novel noun generalization tasks. Waxman and Markow's results also suggest that infants can abstract the category-relevant similarities across instances such as bears, ducks, lions, and dogs. But these results do not show that the relevant similarities include overall shape. Indeed, several recent studies suggest that infants younger than 18 months may not use overall shape when categorizing but instead may focus on specific predictive features such as eyes, head, and legs (Cohen & Cashon, 2003; Quinn & Eimas, 1996; Rakison & Butterworth, 1998). Thus, the extant evidence shows an early link between naming and categorization, but one that may only later become fine-tuned to a specific link between naming and overall shape.

Studies of very young children's mapping of novel nouns to objects also hint that lexical generalization by shape may emerge, but perhaps much earlier than the traditional literature on the shape bias suggests. The key study is by Woodward, Markman, and Fitzsimmons (1994). They presented 13- and 18-month-old infants with a novel object, a strainer, and named it with a novel name ("this is a ____"). They then tested children's learning in two comprehension tasks: a mapping task in which the target object was identical to the original exemplar, and a generalization task in which the target object was from the same adult lexical category (also a strainer) but differed in color from the exemplar. In the task, the exemplar was named and the child was asked to choose between the target and distracter. The distracter object differed on multiple dimensions from the originally named exemplar. In three of four experiments, the 13-month-olds systematically mapped the name to the identical target object but not to the generalization object. The 18-month-olds, in contrast, more consistently mapped the name to the identical object and generalized it to the non-

identical target. These results are interesting for two reasons. First, they suggest growth between 13- and 18-month-olds in generalizing a novel name to instances similar, but not identical, to the original exemplar. Second, because the generalization test objects were highly similar to the original exemplars in shape, they suggest (although they do not conclusively show) a perhaps budding shape bias as early as 18 months, at least 6 months earlier than has been reported in other studies of a shape bias (Imai & Gentner, 1997; Landau et al., 1988; Soja, 1994).

Several recent studies also suggest that there might be a direct link between early attention to shape and the rate of new noun acquisitions. Smith et al. (2002) conducted an experiment in which 17-month-old children were taught the names of novel objects in four artificial categories organized by shape. After eight weekly sessions of training, children demonstrated a generalized bias to shape that was associated with a dramatic acceleration in vocabulary growth outside of the laboratory, a result that has also been replicated and extended by Samuelson (2002). The results suggest that young children form generalizations across known lexical categories organized by shape and use that knowledge to learn more rapidly new lexical categories also organized by shape. The contribution of a shape bias to the rapid acquisition of novel object names is also supported by indirect evidence from Jones (2004), who tested a group of late-talking children, ages 2 1/2 to 3 years on a similar novel name extension task. She hypothesized that children who are slow to acquire an object name vocabulary should also fail to show a shape bias. As predicted, late talkers did not systematically extend the name to shape-related test objects. These results implicate a link between attention to shape and the rate of early noun learning. The following longitudinal study was specifically designed to examine this relationship.

Shape as a Factor in the Rate of New Noun Acquisitions?

Most global descriptions of early vocabulary growth report that for the majority of children, development proceeds from a slow and gradual increase in the number of new words produced to a faster and more noticeable increase (Bates, Bretherton, & Synder, 1988; Benedict, 1979; Dromi, 1987; Gershkoff-Stowe & Smith, 1997; Goldfield & Reznick, 1990; Gopnik & Meltzoff, 1987; Lifter & Bloom, 1989). This increased rate has been called the *naming explosion* or *vocabulary spurt*. Early researchers often conceptualized this change in rate in terms of a qualitative shift in some underlying process (e.g., an

insight that objects have names; McShane, 1979). Under this conceptualization, a rate shift was often located at a particular point in development, measured as the first substantive jump in vocabulary. For example, Lifter and Bloom (1989) proposed as a marker of the vocabulary spurt the first week children added 3 new words to their productive vocabulary, given a minimum of 20 words in the lexicon, whereas Mervis and Bertrand (1994) defined the spurt as 10 new words within a 14-day period, including at least 5 object words. These points typically converge at a time when children are between 18 and 20 months of age and have a productive lexicon of 50 to 100 words. This first substantive jump in vocabulary has also been correlated with a number of other cognitive advances, including categorization (Gopnik & Meltzoff, 1987), object play (Lifter & Bloom, 1989), and object permanence (Corrigan, 1978).

Recent research suggests that this conceptualization of the vocabulary spurt as having a singular, punctuate starting point is probably wrong. Although some children show a readily identifiable shift in the rate of new word productions, others show a steady but more gradual rise (Goldfield & Reznick, 1996; Mervis & Bertrand, 1995; Reznick & Goldfield, 1992). That is, newer conceptualizations of productive vocabulary growth suggest a continuous and smoothly accelerating curve with no one magic moment (Bates & Carnevale, 1993; P. Bloom, 2000; van Geert, 1991). Furthermore, the increasing rate of vocabulary growth appears to involve all kinds of words, not just nouns (Bates et al., 1988; Bloom, Tinker, & Margulis, 1993; Lieven, Pine, & Barnes, 1992). This is relevant because many of the cognitive markers linked to the onset of the naming explosion have involved children's knowledge of object categories as if some underlying advance in object category knowledge was the principle force behind productive vocabulary growth. This idea is seriously weakened by the fact that the acquisition of other kinds of words shows an accelerating function as well. Indeed, the extant literature suggests that many developmental advances contribute to this sustained acceleration in new word acquisitions, including changes in articulation, the perception of speech, and memory retrieval (Gershkoff-Stowe, 2001; Leonard, Schwartz, Morris, & Chapman, 1981; Stoel-Gammon & Cooper, 1994; Vihman, Velleman, & McCune, 1994), as well as changes in children's knowledge about objects and categories. The proper empirical issue, then, is to understand how specific developmental achievements contribute to the changing rate of new word acquisitions.

Our question in this paper is how increased attention to shape may contribute (as one of many factors) to the rate at which children acquire new nouns. If learning to attend to object shape in naming tasks does any real work for the child, it should be a contributing factor to this accelerating pace. That is, if attending to the shape of newly encountered objects helps children pick up category-relevant information, there should be an increase in children's object name acquisitions at about the same time that they systematically begin to attend to shape. If such a relationship does not exist, it is unclear as to the developmental value of children's biased attention to shape in novel name generalization tasks.

A Chicken-and-Egg Problem

A strong relation between attention to shape and the rate of new noun acquisition does not, by itself, indicate that attention to shape causes more rapid acquisition of object names. Determining the causal relatedness of vocabulary growth and the development of a shape bias is difficult because many of the nouns children learn early refer to categories of things that are similar in shape. Samuelson and Smith (1999) investigated the category structure of the 312 nouns on the MacArthur Communicative Developmental Inventory (CDI). These nouns were generated through large normative studies and specifically included the nouns known by 50% of children at age 30 months (Fenson et al., 1993). Samuelson and Smith (1999) found that most of these early-learned nouns (about 67%) refer to solid things in shape-based categories. That is, the nouns that dominate children's productive vocabularies are (though not exclusively) nouns that refer to categories well organized by shape. This raises the question of whether children learn these kinds of nouns because they have a shape bias that predates lexical learning or whether children develop a shape bias because they learn nouns well organized by shape. One possibility is that the causal arrow works in both directions. Children may begin lexical learning with a prelinguistic bias to attend to shape that potentiates the learning of object names but that is also insufficient to drive systematic performance in the novel noun generalization task, a task that demands that children form a systematic category given evidence on only how one thing is named. A weak prelinguistic bias to attend to shape may potentiate and then be strengthened by the early learning of shape-based lexical categories. In other words, there may be a developmental snowball effect through which a weak shape bias is strengthened, enabling object

name learning to become faster and faster. If this is so, the strength of the shape bias in a novel noun generalization task should be temporally linked to an accelerating function in new noun acquisitions. This is what we test.

Rationale for the Design

The methodological question is how to show a temporal relation between children's increasing attention to shape and their increasing rate of new noun acquisitions. This was an easier question under the conceptualization of a naming explosion as having a starting point on the vocabulary growth curve: One just found that point, found some marker of the hypothesized related cognitive ability, and correlated the two. Although the consensus is that this method was based on a flawed understanding of the vocabulary growth curve, the fact is that the method worked reasonably well in relating vocabulary growth to cognitive changes in other domains, including categorization (Mervis & Bertrand, 1994), object play (Lifter & Bloom, 1989), and memory retrieval (Dapretto & Bjork, 2001; Gershkoff-Stowe & Smith, 1997). That is, although the conceptualization on which the method was originally based may be wrong, the method itself does not depend on the idea of a precise point of developmental transition but rather only on the idea that if the two developmental processes are linked, the rate of change in one should be temporally related to achievements in the other.

In the present longitudinal study, we measured children's increasing attention to object shape in a laboratory task and their rate of new noun acquisitions outside of the laboratory. First, we examined the relation between children's rate of new noun acquisitions and their number of shape responses in the laboratory task. If increased attention to shape facilitates the acquisition of new object names, the number of shape responses in the laboratory should be correlated with the rate of nominal vocabulary growth. Second, we calculated for each child the slopes of each growth curve—a measure of the overall rate of change—and asked whether these are correlated. Finally, we examined the correspondences across the two growth curves. In doing so, we attempted to identify substantive rate changes on each growth curve and to test whether those changes are temporally correlated.

The experiment is a longitudinal study of 8 children spanning the period in which they acquired their first 25 to 100 nouns. Thus, the number of participants is few, but the developmental informa-

tion about individual children is rich. This kind of longitudinal design is necessary to measure the temporal relation between increased attention to object shape and the rate of new noun acquisitions in individual children.

Parents were asked to keep a diary of all of the words their children spoke at home. We chose to use a diary study rather than a checklist so that we could measure not just the typical words that children in general know but the specific words individual children were acquiring. Our decision to use production rather than comprehension as a measure of vocabulary growth is a practical one: It is the only reliable and predictive measure there is. One can measure whether individual children comprehend several particular words, but there are no methods that have been shown to be reliable for estimating all of the words that a young child comprehends (see Tomasello & Mervis, 1994). Although the extant evidence indicates that children comprehend more than they produce, particularly early in word learning (Bates et al., 1988; Benedict, 1979; Gershkoff-Stowe & Hahn, 2004; Goldin-Meadow, Seligman, & Gelman, 1976), there is no evidence that the kinds —as opposed to the numbers—of nouns produced differ systematically from those comprehended at any age. Thus, productive vocabulary is probably a conservative but unbiased sample of the nouns children know.

To provide insight into the chicken-and-egg problem, we also analyzed the similarity structure of the categories to which these nouns referred. The question we wanted to answer was whether these early-learned nouns refer mostly to categories well organized by shape or whether the early noun vocabularies become shape biased. We used adult judgments to determine the degree to which shape similarity is characteristic of these early-learned categories. These adult judgments are not meant (and are not adequate) as a measure of shape similarity from the child's point of view (see Smith, 2003) but instead are meant as an index of the kinds of similarities potentially discoverable by children as they learn these categories. Our use of adult judgments is predicated on the idea that there is not an accepted objective measure of sameness in shape (Biederman, 1987; Edelman, 1995; Hummel, 2000) and on the idea that sameness in shape is a psychological rather than physical relation. The method we used, adult judgments, is the same as that used by Samuelson and Smith (1999). The present analyses go beyond the previous findings of Samuelson and Smith by providing developmental information about the first 100 nouns rather than a one-shot

analysis of 300 nouns typically learned early. In this way the study can provide information about whether the early noun corpus becomes increasingly shape biased or begins as shape biased. In addition, the present study provides information about the actual vocabularies of individual children rather than the normative set of nouns on the MacArthur CDI. We return to the issue of what counts as sameness in shape in the Discussion.

In addition to the parent diaries, children came to the laboratory every 3 weeks and participated in a noun generalization task. In this way, we assessed children's acquisition of a shape bias when extending an object name to new instances. At each test session in the experiment, the same exemplar object was named with the same name ("This is a dax") and children were asked to indicate to what other unlabeled objects the name also applied. The decision to use the same exemplar and set of test objects at each session was motivated by a desire to make the task as sensitive as possible to a perhaps nascent shape bias. By using the same objects we reduced the distraction of novelty. Furthermore, by the repeated labeling of the same exemplar with the same name over the course of the experiment, we measured more directly children's ability to generalize that name to unlabeled instances rather than their ability to link the name to the exemplar. In our analyses, we examined whether the emerging shape bias in the experimental task was more closely related to the words children know or their time in the experiment (and thus their experience with this set of objects). However, the critical issue for the experiment was whether a shape bias in the experimental task was related to individual children's rate of noun acquisitions outside of the laboratory; the rate of noun acquisitions outside of the laboratory (and thus the correlation) is unlikely to be influenced by the repetition of the exemplar and test objects in the experiment.

Method

The main study is the longitudinal investigation of 8 children. In addition, adults participated in a task in which they judged the category structures of the nouns in children's productive vocabularies.

Child Participants and Diary Records

Participants were 8 Caucasian children (4 male, 4 female) from middle-class, English-speaking families. Participants were recruited from local birth announcements in Bloomington, Indiana. Parents were contacted when their child was 15 months old. The children who participated were a subset of a larger longitudinal study of early lexical learning. These 8 families were asked from that larger sample to participate in the shape bias task, and all of them agreed.

Parents were told about the study and given instructions on keeping an at-home diary of children's spoken vocabulary growth. Parents were asked to record any new words or phrases their child spontaneously produced each day. This included nonstandard words (e.g., "baba" for bottle) as well as onomatopoeia suggesting pragmatic or referential meaning for the child (e.g., "choo-choo"). Parents were also asked to provide information about the context in which children used the words they produced. Parents were contacted weekly by phone about the number of words in their children's productive vocabulary to determine when children should begin laboratory visits. The goal was to have children begin the laboratory sessions after they had started producing some nouns but before they had 25 nouns in their productive vocabulary and to remain in the experiment until after they had between 75 and 100 nouns in their productive vocabulary. For this characterization of known nouns, all nouns (object names, proper names, mass nouns, and names referring to abstract concepts such as *friend*) were included.

Table 1 presents the mean and ranges of the ages, number of total words, and number of nouns in productive vocabulary at the start of laboratory visits and at the end of the experiment. As is apparent, the children's ages and rates of vocabulary growth varied considerably. Given the different rates of vocabulary growth, individual children participated in a different number of experimental sessions in the laboratory and reached different levels of vocabulary development. The mean number of laboratory visits

Table 1

Productive Vocabulary and Ages (in Months and Days) of Children at the Start and End of Study

	First session	Last session
Age		
M	17 m 17 d	21 m 14 d
Range	16(3) to 20(3)	18(18) to 23(26)
Total words		
M	38.4	134.4
Range	27 to 62	82 to 194
Nouns		
M	16.5	86.0
Range	10 to 24	52 to 123

was 6; the range was 4 to 8. Thus, individual children were in this longitudinal study for a minimum of 3 months and for a maximum of 6 months.

The 8 children came to the laboratory every 3 weeks and participated in a noun generalization task. The stimulus set consisted of an exemplar and five test objects. The exemplar was roughly U-shaped and made of wood. Its width and height were approximately 5 cm and its thickness was 1.5 cm. It was coated with haphazard splatters of bright red, green, blue, and white paint. Of the five test objects, two matched the exemplar in shape and differed from it in material and coloration: One was made of red wire mesh and the other was made of blue sponge. The three other test objects differed from the exemplar in shape. One of these matched the exemplar only in the splatter coloration; it was a moon-shaped bean bag. One matched the exemplar in material only; it was a wooden triangle painted blue. Finally, one test object matched the exemplar in both coloration and material and differed from it only in shape; it was a wooden object roughly Z-shaped of the same splatter coloration as the exemplar.

Children saw these same six stimuli at every visit and the procedure during each visit was the same. The parent and child sat on a couch across a low table from the experimenter. The experimenter showed the child the exemplar and told the child, "This is a dax." Then the experimenter laid the exemplar and the five test objects (which were never named) on the table and encouraged the child to play with them for 1 min. The experimenter held up the exemplar object again and said several times, "This is a dax." Then the experimenter held the exemplar in one hand, extended her other hand palm up and said several times, "Give me a dax," or "Can I have a dax?" The experimenter waited 30 s for a response. If the child handed an object over, the experimenter held onto that object and asked, "Is there another dax? Get me another dax." The experimenter waited 30 s for a response. The experimenter provided no feedback, either positive or negative, concerning children's choices but just took them matter of factly.

Parents were asked to bring the at-home diary to each laboratory visit and were interviewed about the words produced by their child in that 3-week interval and the contexts in which the words were produced.

Adult Judgments of the Category Structure of the First 100 Nouns

Twenty undergraduates (15 female, 5 male) participated in a task asking them to judge the category structure of the nouns in the children's productive vocabulary. Participants volunteered to participate as part of a course project in an advanced laboratory class at Indiana University. The sample was primarily Caucasian.

A list was assembled of all of the nouns (excluding proper names) that parents reported to have been produced by the children in the study. There were 213 nouns on the list. We asked each of the adults to judge the category structure of each noun. We used the same procedure as Samuelson and Smith (1999). The nouns were organized into broad semantic categories (animal, artifact, food, people) and presented to participants in one of two pseudo-random orders (preserving the broad semantic categories). For each noun, the adults were asked to think of typical instances of each named category. With these instances in mind, they were asked three yes–no questions about the categories: (a) "Are the things named by this noun typically similar in color?" (b) "Are the things named by this noun typically similar in shape?" (c) "Are the things named by this noun typically similar in material (that is, in what they are composed of)?" We did not define "typical" or "similar" for the adult judges but purposely sought their intuitions on category composition.

From these adult judgments each lexical item was designated as shape based, color based, or material based if 75 % (i.e., 16 of 20) of the adults judged the members to be similar on that property. We set this conservative criterion to be confident when we labeled a category as, for example, *shape based* that the within-category similarity in shape was sufficiently strong that most people would agree it existed. Note that by our method individual lexical categories could be designated as organized by none of these properties (if less than 75% of the adults agreed on one of the three possible kinds of similarities), by one of these properties (if 75% or more of the adults agreed on that within-category similarity), or by several of these properties (if 75% or more of the adults agreed on one similarity and 75% or more of the adults agreed on the other). For example, by these criteria, *crayon* is a shape-based and a material-based lexical category whereas *car* is a shape-based category. Nouns, such as *crayon*, that were judged as well organized by more than one property were counted as instances of both kinds of organizations. For example, in counting the number of shape-based categories for a child, *crayon* was included; and in counting the number of material-based categories, *crayon* was also counted. By characterizing a category as shape based in this way, we mean no more than that adults judged the category to consist of

similarly shaped things. In the following analyses, we use these designations of individual lexical items to determine the properties of individual children's noun vocabularies at various points in lexical development. That is, we asked how many nouns and what proportion of nouns known by an individual child refer to shape-based categories and we asked how this knowledge relates to individual children's generalization of a noun to new instances.

Results

We analyze the results in three steps. First, we present evidence on the character of these early-learned nouns. Second, we present data on children's performances in the novel noun generalization task. Third, and most important, we examine the relation between individual children's productive vocabulary growth and their extension of the exemplar's label in the laboratory task.

Early-Learned Nouns

Table 2 lists the frequencies of lexical items of several conceptual kinds at three levels of vocabulary development: 0 to 25, 26 to 50, and more than 50 nouns. When children produced fewer than 25 nouns, most of those nouns were names for artifacts, animals, or proper names. As the number of nouns in productive vocabulary increased, the biggest percentage increase was in names for artifacts—words such as *car, ball, pen, cup,* and *book.* The fact that artifact terms dominate new acquisitions is interesting because several theorists have suggested that artifactual categories are those most robustly organized

by shape (Jones & Smith, 2002; Keil, 1994; Soja et al., 1991). The composition of the noun corpus observed here fits well with prior descriptions of the structure of early noun vocabularies (e.g., Anglin, 1977; Dromi, 1987; Nelson, 1973).

We next compared the rate of growth for noun categories judged to be shape based by the adult judges with the rates of growth for other nouns and non-nouns. Figure 1 shows the mean number of new words of each kind added each week during the three periods of productive vocabulary development. The rates (new words per week) of growth for count nouns, other nouns, and non-nouns all accelerate as children move from knowing fewer than 25 nouns to more than 50. But after children produce about 26 total nouns, the rate of acquisition of shape-based nouns outpaces the rate of acquisition of all other kinds of words. This conclusion was confirmed by submitting the rates of new word acquisitions to a 3 (vocabulary size) $\times$ 3 (kind of word) repeated measures analysis of variance (ANOVA). The analysis yielded a main effect of vocabulary size, $F(2, 14) = 37.36$, $p < .001$, and kind of word, $F(2, 14) = 38.22$, $p < .001$, and a reliable interaction between vocabulary and kind of word, $F(4, 28) = 4.00$, $p < .01$. Post hoc analyses (Tukey's, $\alpha = .05$) indicate that at the earliest period (0–25 nouns) of vocabulary development, the rate at which new count nouns, other nouns, and other words were added did not differ reliably. During the second period (26–50 nouns), the rate of new count noun acquisitions was reliably
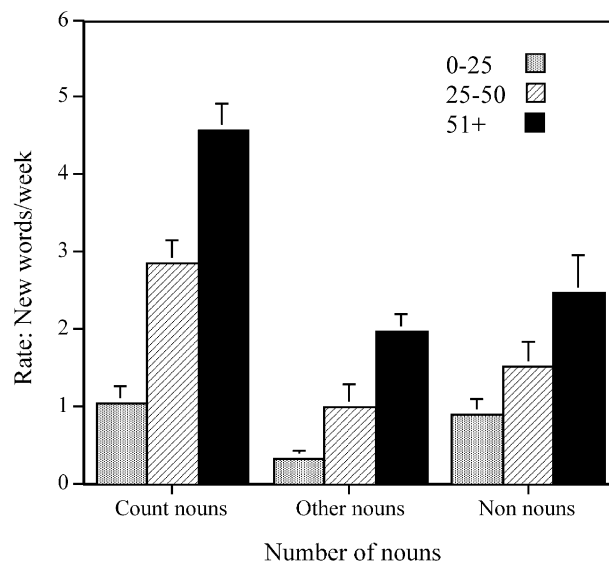
Table 2
Mean Cumulative Types of Nouns in Children's Productive Vocabulary at Three Levels of Productive Vocabulary Development

	0 to 25 nouns	26 to 50 nouns	50+ nouns
Proper names (includes mama, dada)	4.25	6.50	9.88
Character names (e.g., Big Bird)	0.00	2.00	5.00
Other people (e.g., fireman, boy)	1.00	1.38	1.75
Artifacts	7.50	17.60	32.75
Animals	4.90	8.62	12.25
Food	3.00	6.25	10.88
Body parts	1.62	2.50	4.87
Other (e.g., dirt, wind, snow)	0.62	3.00	7.00

Figure 1. Rate of new word acquisitions (by parent report) when children had 0 to 25 nouns (count, mass, and proper), 26 to 50 nouns, or more than 50 nouns.

greater than the rate of new acquisition of other nouns, and by the third period (50–100 nouns), the rate of new count noun acquisitions exceeded that of both other nouns and non-nouns. That is, the rate of new count nouns increased more over the course of the study than did other word kinds. In the course of early productive vocabulary growth, the growth curve for count nouns accelerated more than the growth curves for other kinds of words.

However, children's noun vocabularies also show remarkable stabilities during this period of growth. Past research indicates that count nouns that refer to object categories are the categories most likely to be organized by shape (Samuelson & Smith, 1999; Soja et al., 1991). Accordingly, we next classified the nouns by syntactic kind using the criteria in Table 3 (see also Gathercole & Min, 1997). Table 4 presents the proportion of all nouns that were of the four syntactic kinds: proper, count, mass, and other. As is apparent, at each stage of development, the majority of early-learned nouns are count nouns. Table 4 also presents the proportion of count nouns that were shape based according to the adult judgments and criteria described earlier. As can be seen, almost all of the count nouns children produced refer to objects that adults judged to be in shape-based categories. Moreover, the proportion of count nouns that referred to shape-based categories was greater than .78 for each child at each level of vocabulary development. Thus, children's early noun vocabularies overall and the count noun vocabularies in particular appear to be biased toward shape-based categories right from the start.[1]

Noun Generalization Task

Dependent variables. Children's performances in the novel noun generalization task were assessed in

Table 3
Criteria for Categorizing Nouns

Type of nouns	Description of nouns
Proper	Cannot be preceded by an *a* or by numerals, has no plural form, cannot be preceded by *much.*
Count	Can be preceded by *a* and numerals, has plural form, cannot be preceded by *much.*
Mass	Cannot be preceded by *a* or by numerals, has no plural form, can be preceded by *much.*
Other	Items such as *cake* that occur in mass and count form; character names such as *Ernie* that may be used as proper names or with count syntax.

Table 4
Proportion of Total Nouns of Four Syntactic Kinds as a Function of the Three Levels of Productive Vocabulary Development and of Count Nouns That Were Judged by Adults to Refer to Objects in Shape-Based Categories

Nouns in productive vocabulary	Kinds of nouns				Count nouns judged to be shape based
	Count	Proper	Mass	Other	
0 to 25	.73	.18	.06	.02	.98
26 to 50	.70	.14	.06	.08	.94
More than 50	.68	.08	.10	.14	.93

terms of three dependent measures. The first was children's choice of test objects when asked to "get a dax" and "another dax." If children interpreted the novel object name as referring to a category of similarly shaped things, they should have responded to these requests by choosing test objects that were the same shape as the exemplar from among the set of five test objects. The second dependent measure was children's spontaneous labeling of a test object with the novel name. The child was credited with spontaneously generalizing the name to a test object if the child said the name while unmistakably looking at that test object or if the child said the name while holding up a test object and showing it to the experimenter or parent. The third dependent measure was spontaneous grouping of test objects with the exemplar. Recall that at the beginning and end of the experimental session, the exemplar and all five test objects were presented and the child was allowed to play with them. During this time, the children often grouped objects together. We counted the grouping of test objects with the exemplar. For example, if the test object that matched the exemplar in material only was paired with the exemplar, the child was credited with a material grouping. A pair was considered grouped only if the child intentionally put the objects together in close spatial proximity (e.g., one on top of the other, side by side, two objects held up and jointly showed to parent or experimenter).

Two coders, naive to the experimental hypotheses, coded all videotaped sessions for these behaviors and each independently coded the same randomly selected sample of 25% of those sessions. The coders agreed 100% of the time on the test object chosen (or lack of response) by the child in response to the request to "get a (another) dax." They agreed 96% of the time on spontaneous productions of "dax" and 97% of the time on the object to which the child was referring when the name was offered. The coders agreed 87% of the time on the number of
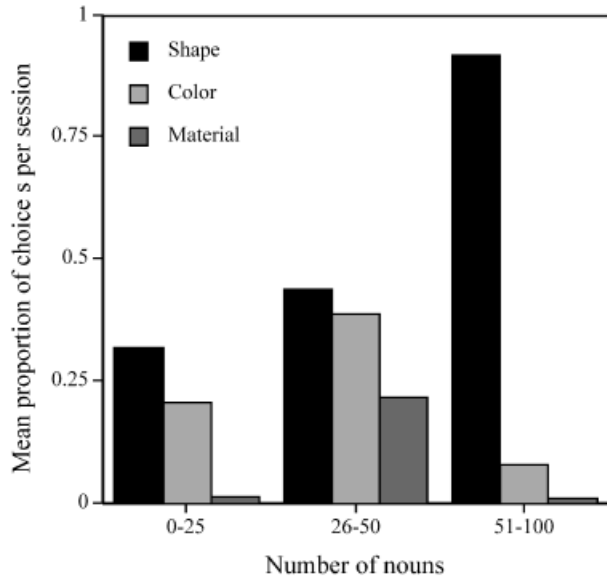
Figure 2. Mean number of shape choices in noun generalization task as a function of the number of nouns in the children's productive vocabulary.

exemplar-test object pairs spontaneously formed and 100% of the time on the items in those groups. All differences in judgments were resolved by reviewing the tapes and by discussion.

Shape choices. Figure 2 shows the mean proportion of times the child responded to both of the experimenter's requests for "a dax" by choosing a test object that matched the exemplar in shape as a function of the three periods of productive vocabulary growth. For comparison, the mean proportion of choices that were color choices and material choices are shown (the test object that matched the exemplar in both color and material is included under color). As is apparent, shape choices increased substantially as the number of nouns in the children's productive vocabulary increased, $F(2, 14) = 12.16$, $p < .001$. Children's nonshape choices first rose and then fell as vocabulary increased, $F(2, 14) = 4.42$, $p < .05$. Furthermore, as can be seen in the figure, when children had fewer than 25 nouns in their productive vocabulary, they only rarely responded to the experimenter's request for "a dax" and when they did so, handed over test objects that matched in other properties as well as those that matched in shape. When the children had between 26 and 50 nouns in their vocabulary, they typically responded to the experimenter's request by handing over an object, but again, they were equally likely to choose an object that matched in material or color as one that matched in shape. However, after children knew more that 50 nouns, they selectively responded to the

experimenter's requests by choosing the test objects that matched the exemplar in shape. These results suggest that biased attention to shape emerges with development but does so early in word learning, when children have between 50 and 100 nouns. This is the earliest experimental demonstration of a shape bias in a novel noun generalization task.

As can be seen in Figure 3, children frequently labeled the exemplar "dax," the same object they heard the experimenter label "dax." Moreover, despite the fact that there were only two shape-matching test objects but three non-shape-matching test objects, children labeled the shape-matching test objects as "dax" more than they did the non-shape-matching test objects. An ANOVA of these data yielded main effects of vocabulary size, $F(2, 14) = 20.67$, $p < .001$, and stimulus, $F(2, 14) = 38.24$, $p < .001$, and a reliable interaction between vocabulary size and stimulus, $F(4, 28) = 8.08$, $p < .001$. As children's vocabulary grew, they became increasingly likely to use "dax" as a label and were more likely to use the term to label the exemplar than the test objects. However, after the children had more than 50 nouns in their productive vocabulary, they also generalized the word "dax" to the shape-matching test objects.

The third dependent measure was spontaneous grouping of test objects with the exemplar. Objects were considered to be grouped together only if the child intentionally put the objects together in close spatial proximity. Figure 4 shows the mean frequency per session of such groups. Overall, the
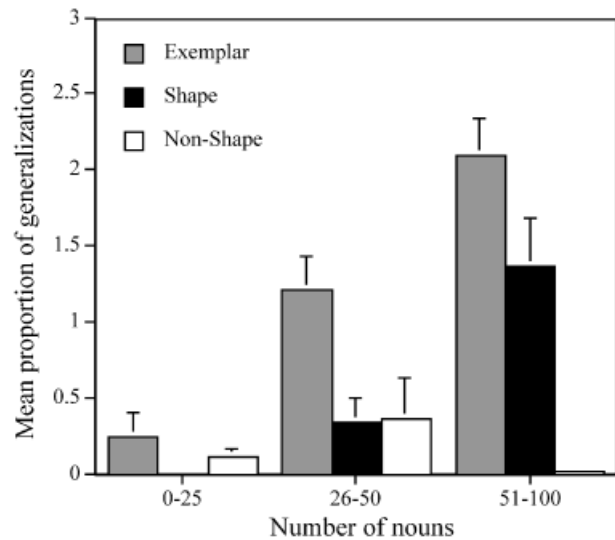

Figure 3. Mean number of spontaneous productions of the experimental name used to refer to the exemplar, the shape-matching test objects, and the non-shape-matching test objects as a function of the number of nouns in the children's productive vocabulary.
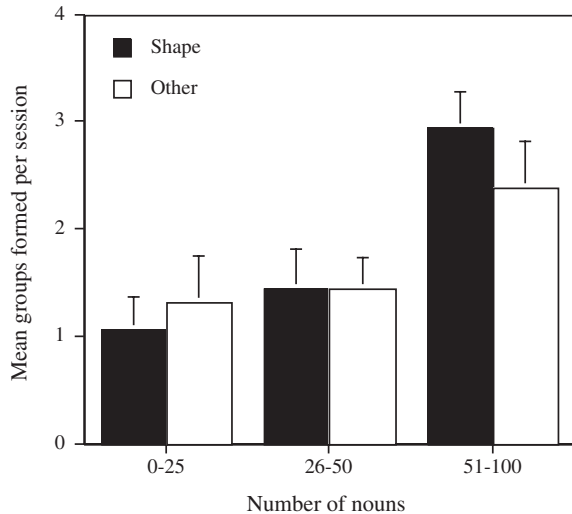
Figure 4. Mean number of shape-based and non-shape-based groups formed by the children in the noun generalization task as a function of the number of nouns in the children's productive vocabulary.

number of grouping behaviors increased as children's vocabularies grew, $F(2, 14) = 6.08$, $p < .01$. However, as shown in Figure 4 and as supported by a reliable interaction between vocabulary size and kind of group, $F(2, 14) = 4.13$, $p < .05$, shape-based groupings became more dominant over the experiment.

These three dependent measures—choices in response to the experimental question, spontaneous labeling of the objects, and spontaneous grouping—all suggest an early shape bias at a much younger age than previously reported. It is likely that this early demonstration of a shape bias is due to children's repeated visits to and comfort in the laboratory and their repeated experiences with the novel name, the exemplar, and test objects—contexts perhaps closer to everyday vocabulary learning than most novel name generalization experiments. Thus, these in-laboratory experiences may have helped a nascent shape bias show itself.

This raises the question of whether children's shape responses in the experimental task are more strongly related to time in the experiment (a training effect) or to the number of nouns they know or, perhaps, to age. To address this question, we determined the total number of shape responses by each child on that child's last three sessions of the experiment and determined the correlations between that measure and the number of sessions in the experiment, the number of nouns in the child's vocabulary, and age. We used the number of shape responses over the last three sessions to ensure sufficiently

broad between-subject variation on this variable. The number of shape responses was correlated with the number of nouns in each child's vocabulary, $r(8) = .68$, $p < .05$, one-tailed, but not with number of sessions, $r(8) = .03$, or with age, $r(8) = -.38$, $p > .05$, one-tailed. Thus, the emerging shape bias appears more closely related to vocabulary growth than to time in the experiment or time in the world.

Rate of New Noun Acquisitions and the Emergence of the Shape Bias

Figures 5 and 6 show the individual growth curves for nouns and shape responses in the experiment. The key question is whether, for individual children, the two growth curves line up. Is change in the rate of acquisition of new nouns related to increasing attention to shape? First, we asked simply whether children who attended to shape more over the course of the experiment had faster rates of new noun acquisitions over the course of the experiment. They should if attention to shape aids noun learning. To address this question, we calculated the rate of new noun acquisitions (nouns per week) for each child over the course of the experiment and the number of shape responses per session over the experiment. These were strongly correlated, $r(8) = .70$, $p < .05$, one-tailed. Thus, over the course of the experiment, greater attention to shape was associated with increased rates of new noun acquisition. The implication is clear: The shape bias, as measured in experimental tasks, predicts children's development outside of the laboratory. Attention to shape, however, should be most beneficial to learning new count
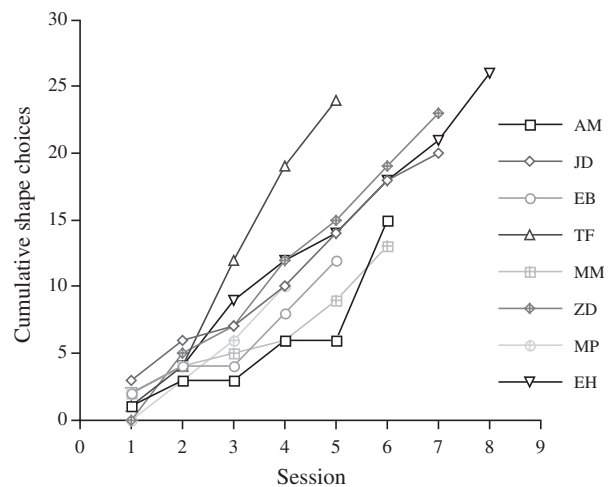

Figure 5. Cumulative growth curves for individual children for shape responses over the course of the experiment.
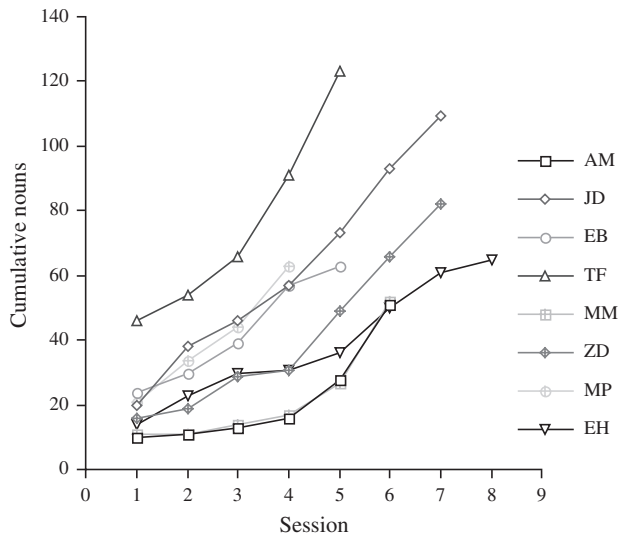
Figure 6. Cumulative growth curves for individual children for the number of new nouns acquisitions as a function of session.

nouns as these are the categories most typically well organized by shape. Accordingly, we also calculated the correlation between the rate of new count nouns and shape responses over the course of the experiment and the rate of acquisition of noncount nouns and shape responses. These were $r(8) = .75$, $p < .05$, one-tailed, and $r(8) = .20$, respectively. Thus, children's attention to shape specifically predicts new count noun acquisitions.

Second, we asked how the rate of change across one growth curve was related to the other by calculating for each child the slope of his or her noun growth curve and shape growth curve. These were strongly correlated, $r(8) = .80$, $p < .05$, one tailed. Children with steeper vocabulary functions also showed steeper functions of increasing shape responses over the course of the experiment. Again, this relation should be stronger for count nouns than for other nouns. This prediction was confirmed. The slopes of the count noun acquisition curves for each child were more strongly related to the slopes of the shape growth curves, $r(8) = .81$, $p < .05$, than were the slopes of the other noun growth curves, $r(8) = .18$. Thus, children who attended to shape more and who more rapidly increased their attention to shape during the course of the experiment also more rapidly acquired new count nouns.

The last converging measure asks whether there is a temporal association between systematic attention to shape in the experimental task and a marked increase in the rate of new noun acquisitions. For this measure, we determined two transition points for each participant: the first session at which the child

showed a systematic shape bias in the experimental task and the first session at which the child showed a substantive increase in his or her rate of new noun acquisitions outside of the laboratory. We defined the session at which the child first showed a systematic shape bias in response to the request for a "dax" as the first session in which the child selected a shape matching test object on two of the two requests to indicate "a (another) dax." The probability that a child could earn such a score by chance alone is .10. We defined the session at which a child first showed a substantive increase in the rate of new noun acquisitions as the first session at which parents reported an increase of 10 or more new nouns in the 3-week intersession period. This criterion is consistent with previous measures under the traditional conceptualization of the vocabulary spurt (Gershkoff-Stowe & Smith, 1997; Goldfield & Reznick, 1990; Gopnik & Meltzoff, 1987; Lifter & Bloom, 1989).

At issue is whether these two measures temporally align. Do individual children in the experimental task systematically extend the exemplar's name to the test objects by shape at the same point at which there is a noticeable increase in the rate of new object name acquisitions? Because these questions concern the temporal relatedness of these two measures for individuals, we show the data for each child in Table 5.

The first two columns show the session at which the significant increase in new noun acquisition occurs (as previously defined) and the session at which a systematic shape bias in the task first emerges. As can be seen, these are temporally close and do not differ reliably, $t(7) = 1.16$, $p > .05$. For all but 1 child, the shape bias emerged within one session (+/−) of the defined increase in rate of vocabulary growth. Furthermore, these two transition points were highly correlated, $r(8) = .85$, $p < .01$, one-tailed. This close temporal link suggests that the noun generalization task used in this experiment is measuring an achievement that is developmentally related to real-world noun learning. That is, significant changes along one curve are temporally correlated with significant changes on the other.

As a further measure of the temporal link between increasing acquisition of nouns and attention to shape, we partitioned the experimental sessions into those before and after the first session in which children had gained 10 new productive nouns in a 3-week period. If this point on individual children's vocabulary growth curve relates to a corresponding change in children's attention to shape, before this point we should see, for each child, few shape responses in the experimental task and after it, many.

Table 5

Measures of the Temporal Relations Between Individual Children's Vocabulary and Shape Growth Curves

Child	Rate-shift session	Shape-bias session	Age at rate shift (mos)	Number of nouns at rate shift	Number of count nouns at rate shift	Proportion of shape choices preshift	Proportion of shape choices postshift
1	3	3	17.87	44	38	.50	1.00
2	5	7	17.40	73	48	.33	0.75
3	3	3	18.33	66	35	.12	0.69
4	4	4	22.57	57	32	.10	1.00
5	5	5	22.07	27	16	.19	0.75
6	5	6	23.03	28	14	.19	0.75
7	5	4	17.87	49	33	.25	0.75
8	6	7	20.43	50	34	.35	1.00
M	4.50	4.88	19.90	49.25	31.25	.25	0.84

The last two columns in Table 5 show the mean proportion of shape choices before our identified marked increase in new noun acquisition and after. For each child there is a dramatic shift in shape responses from before the rate shift to after, $t(7) = 11.39$, $p < .001$.

Table 5 also shows the ages of the children and the number of count nouns and noncount nouns at the so-defined rate-shift session. As is apparent, children varied in age, from 17 to 23 months and some children reached this developmental point as early as Session 3 and some as late as Session 6. Furthermore, the number of nouns in productive vocabulary ranged from a low of 27 to a high of 73, and the number of count nouns ranged from a low of 14 to a high of 48. These are earlier points than suggested by the more global grouping of sessions by vocabulary in Figures 5 and 6, a reminder of the value of attending to individual patterns of development.

The wide individual variability in the number of nouns in children's vocabulary at the time of converging changes in the shape bias and rate shift in vocabulary and count nouns growth also raises important questions about checklist measures of children's vocabulary. The MacArthur CDI, which we used here, has become a popular measure because it is easy to administer, highly reliable, and a strong predictor of children's performances in a variety of language tasks (Fenson et al., 1993). However, the measure asks only whether a child produces a word, not how well that word is known or what the range of instances is to which that word is applied. A better understanding of the developmental mechanisms underlying the relationships observed here may require better assessments of children's lexical categories than whether they merely say a word. What is needed are measures of the frequency of word use,

their application to few or many instances, the properties of labeled (and unlabeled) instances, and the context in which the production occurred. We have begun preliminary steps in developing such an instrument.

Nonetheless, even with this limitation, the data from individual children suggest that increased attention to shape is strongly linked to the accelerating pace of new noun acquisitions typically observed during the developmental period from 17 to 20 months.

Discussion

There are three main findings that provide new insights and raise new questions about the developmental processes that underlie growth in attention to shape and growth in the noun lexicon. First, the earliest nouns that children learn predominantly refer to things that are similar in shape. The new finding is that this is true for even the first 25 nouns that children acquire. Thus, the dominance of categories judged to be shape based by adults is not just a statistical fact about a statistically normative vocabulary but rather is a fact about the earliest nouns that children learn. This is also a fact that raises serious issues about the origins of the shape bias in novel noun generalization and about why early noun categories are structured as they are.

Second, as children's nominal vocabularies increase, their attention to shape in laboratory tasks also increases. Specifically, children become increasingly likely to extend object names by shape, to label spontaneously objects by their shape, and to group objects by shape. We observed this heightened attention to shape at least 6 months earlier than previous experimental demonstrations of the shape

bias. Moreover, the present experiment shows that in individual children this increasing attention to shape is strongly linked to the number of nouns in children's productive vocabularies and is more strongly linked to vocabulary than to either time in the experiment or to age. As children move from fewer than 25 nouns in productive vocabulary to nearly 100, they increasingly attend to shape in naming tasks. These results suggest a developmental link between increased attention to shape and early noun learning, but they do not specify the causal underpinnings for that link.

Third, the results show corresponding changes in children's attention to shape in the laboratory tasks and in their rate of new noun acquisitions outside of the laboratory. For individual children, increased rates of new noun acquisition were related to increased attention to shape, and indeed, consistent name extensions by shape in the experimental task emerged within one session of a pronounced increase in the rate of new noun acquisitions. The data, however, do not specify the causal nature or direction of the link between early vocabulary and attention to shape.

The Directionality Problem

The entire pattern clearly presents a chicken-and-egg problem. Increased attention to shape could cause children to acquire names for things similar in shape, and acquiring names for things similar in shape could increase attention to shape. One seemingly key fact to resolving this directionality issue is the finding that children's earliest noun vocabularies—when they produce less than 25 nouns—are dominated by categories of similarly shaped things.

This fact is consistent with the idea that children's perceptual systems are cued to pick out bounded whole objects with stable shapes, an idea offered by Gentner (1982) in her natural partitions hypothesis (see also Spelke, 1990). The data are also consistent with the idea that children are initially unbiased learners and that the statistical structure of their earliest vocabulary simply reflects the statistical structure of the words they hear. Analyses of the nouns parents use in speech to children support this idea (Sandhofer et al., 2000). Most of the nouns that children hear, like the nouns they produce, refer to categories of similarly shaped things. (Passing the cause down to the structure of the input, of course, begs the question as to why the input has the structure it does, an issue to which we will return.)

The present data cannot distinguish these two hypotheses about the origin of the shape bias in noun learning. However, and importantly, the data do offer insights beyond the origin of the shape bias, insights beyond the question of whether it begins with a prelingual shape bias of some form or begins with word learning. Specifically, the results offer insights into the developmental relation between attention to shape and noun learning. Whether a shape bias is there from the beginning, or whether it originates in noun learning, it also develops, becoming stronger over the course of early word learning. Moreover, these changes in the strength of the shape bias are tightly linked to changes in children's rate of acquisition of new object names. Beyond the question of origins, then, is the question of development and how and why changes on these two developmental trajectories are so closely related.

Development is progress in time such that advances at each moment constrain or facilitate what the child will learn in the next moment (Gershkoff-Stowe & Thelen, 2004). Thus, each new object name learned that refers to a category of similarly shaped things (whatever the reason behind the learning of that category) seems likely to increase (even if slightly) children's future attention to the shapes of things in naming tasks. Furthermore, increases in attention to shape (whatever the reason behind that increase) seem likely to facilitate children's future acquisition of names for similarly shaped things. In this way, the causal arrow that creates the two growth curves may go in both directions, with—at every step in time—advances in one fostering advances in the other.

What is the best way to understand this developmental codependency? The mutual causality is understandable if one thinks of the shape bias not as an ability that suddenly comes on-line (or as knowledge structures that the child does or does not have) but rather as a continuously increasing propensity, just as the number of object names in a child's vocabulary is a continuously increasing function. For the question of development, as opposed to origins, the chicken-and-egg metaphor is perhaps inappropriate. Neither development turns into the other; rather, they codevelop. Codependency between two mutually reinforcing processes has been studied in formal theories of growth and change (van Geert, 1991). Systems such as these, composed of components that positively influence each other, yield a self-accelerating growth function, the very pattern observed here. Thus, the finding that the shape bias is linked—not just to increasing noun acquisitions but to an increasing rate of growth—supports the idea of bidirectional causality.

Shape and Other Words

If attending to shape and learning nouns are mutually reinforcing trends that feed on each other to strengthen attention to shape and to increase noun learning, how is it that children ever break away from shape to learn other kinds of words? This question presumes that development is a zero-sum game, that doing one thing well necessarily means doing other things poorly. But development is definitely not like this (advances in mathematical concepts, for example, do not predict failures in language). In this context, it is useful to consider one explanation of the mechanisms behind a developmentally increasing shape bias. Smith (2000) has suggested that the shape bias is the result of learned correlations among cues, for example, the social and linguistic cues characteristic of naming events, the perceptual properties of fixed and angular shapes, and lexical categories organized by shape. By this account, then, attention to shape is contextually cued; children will not attend to shape in contexts without these cues. Yet by this account, children can also learn other clusters of correlations and exploit them to learn other kinds of words (e.g., linguistic cues associated with mass nouns, nonsolidity, and lexical categories organized by material). The point is: Learning the correlations that increase object name learning need not imply that children are not also learning the different correlations that facilitate the learning of other kinds of words.

We grant that being a skilled learner of object names could interfere with learning other kinds of words, and probably sometimes does (Au & Laframboise, 1990; Mintz & Gleitman, 2002; Sandhofer & Smith, 2004; Smith et al., 1992). But as children learn more about regularities in their world and in language, they will advance along many fronts. In this context, it may be worth emphasizing that the present results show only that the number of nouns in children's productive vocabulary (and the rate of additions of new nouns) is developmentally linked to the shape bias. These two trajectories are related, but the data make no predictions one way or the other about whether these advances will compete with or even foster the acquisition of other kinds of words (Bates & Goodman, 1997; Samuelson, 2002).

These issues are also relevant to one seeming puzzle in the present results: increasing rates of learning new object names but a constant, even declining proportion of shape-based words in total vocabulary. As development progresses, the extant evidence indicates that children attend to shape in many object naming tasks with increasing regularity, but the portion of shape-based nouns declines as children add more substance terms and more abstract and relational nouns (such as friend). This is understandable if we entertain the possibility that as children become more skilled at learning names for concrete objects they are also (and perhaps independently) becoming more skilled in learning about other kinds of concepts and other kinds of words.

Function and Sameness in Shape

Although the present results show that attention to shape is strongly linked to children's real-world productive vocabulary growth, they do not show why or how shape matters as it does. Why, for example, do so many common object categories consist of things that are similar in shape?

In her now classic analyses of common object categories, Rosch (1973) suggested that shape mattered because global object shape was a strong determiner of what one could do with an object, of its affordances. This same idea is supported by recent neural imaging studies showing a strong link between object recognition and the motor areas involved in acting on objects, and in studies of adult object recognition showing direct influences of ongoing motor activity (related to characteristic actions on those objects) and object recognition (Barsalou, 1999; Creem & Proffitt, 2001). In brief, human languages probably lexicalize the object categories they do because of the functional properties of those objects, that is, because of the actions and uses that their shapes afford.

The relation between object shape and object function may also play a role in the psychological definition of sameness in shape. According to one current theory of shape, Biederman's (1987; Hummel & Biederman, 1992) recognition-by-components model, objects are recognized in terms of abstract geometric components called *geons*. By this account, kitchen chairs and living room chairs have the same shape because they have the same component part structure. In support of this theory, Biederman has shown that adults can recognize common objects given just two to three relevant geons in the proper arrangement. This theory links to the importance of function in the definition of shape because the relevant geons are precisely those relevant to people's use of these objects. It is interesting that Smith (2003) has shown that children's recognition of common objects from their geon structure increased dramatically between 18 and 24 months, suggesting that perceived sameness in shape may be a develop-

mental product of category learning and, possibly, a product of learning about object functions.

If object shape and object function are causally linked, attention to shape should help children pick up category-relevant information about function. Recently, Gelman and Bloom (2000) have suggested the inverse hypothesis, that knowledge about function—and about how objects are designed to meet functional goals—direct children's attention to shape. Thus, again, we have a chicken-and-egg origins problem. But is the origins question the most vital question? Increased attention to shape (for whatever reason) should facilitate learning about design and function. Knowledge about design and function (for whatever reason) should increase attention to object shape. Accordingly, we may gain greater insight into both the role of shape and function in categorization if we empirically study their developmental interplay.

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ENDNOTE

1. The finding of greater absolute rates of new word acquisitions for shape-based words but a constant proportional structure of children's early vocabularies is explainable by the fact that new shape-based words increase at a more rapid rate than other words but do not increase at a greater proportional rate. Absolute rather than proportional rates of change are appropriate because proportional change is highly unstable at values near zero. For example, an increase from 1 to 3 words is a 300% increase whereas an increase from 150 to 300 words is merely a 50% increase.