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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 33(33)

ISSN

1069-7977

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Publication Date

2011

Peer reviewed

Individual vocabulary differences and the development of the shape bias

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Abstract

Researchers have proposed that learning names of individual words and categories leads an individual child to develop a general word learning bias. However, evidence to date comes from studies of group means rather than individuals. The current study tests the prediction that the statistics of an individual child's vocabulary are closely related to that child's development of word learning biases. We demonstrate that individual differences in vocabulary structure predict individual differences in novel noun generalization.

Keywords: vocabulary development, categorization

The literature on early word learning suggests children overcome the difficulties involved in word learning via the use of biases or constraints such as, for example, the tendency to generalize novel names of solid objects by similarity in shape rather than material or color (shape bias) (Landau, Smith, & Jones, 1988). Work on the shape bias suggests that attending to shape is beneficial in that the majority of nouns children learn early in development are names for concrete artifact categories organized by shape similarity (Samuelson & Smith, 1999). The shape bias is fundamentally *developmental*; experimental evidence demonstrates that children begin attending to shape in noun generalization tasks after they have learned some nouns and attention to shape increases with development (Samuelson & Smith, 1999; Gershkoff-Stowe & Smith, 2004).

Smith and colleagues have proposed a four-step process to explain the development of the shape bias from prior learning of individual nominal categories (Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002). According to this proposal, as children learn names for individual instances (step 1) and individual categories (step 2) this regular association of solid things and categories organized by similarity in shape helps them to learn to attend to shape when learning new words for solid objects (step 3). Further, once they have learned to attend to shape, they will learn new words more quickly (step 4).

Support for this proposal comes from longitudinal studies showing that teaching children names of multiple categories organized by similarity in shape helps them develop a precocious shape bias and acquire vocabulary more quickly than those not given such training (Samuelson, 2002; Smith et al., 2002). Furthermore, cross-linguistic studies show that the biases depend on the language (and therefore the specific regularities) being learned (Smith, Colunga, & Yoshida, 2003) and studies of atypical learners (such as children with autism and late-talkers) show that they do not develop the same attentional

biases in word-learning as typically-developing children (Tek, Jaffery, Fein, & Naigles, 2009; Jones & Smith, 2005).

Recent training studies have examined the influence of variability both in the exemplars children see when learning categories (Perry, Samuelson, Schiffer, & Malloy, 2010), and in the statistics within the noun vocabulary children learn (Samuelson & Schiffer, 2011), on the development of the shape bias. Perry et al. (2010) used mixed logistic regression to show how individual children's performance at each step in the four-step process influences what they learn and the bias that develops. Samuelson & Schiffer (2011) found that children taught a vocabulary dominated by count nouns that named solid objects in categories well organized by similarity in shape learned biases differently from children taught a vocabulary containing equal numbers of count and mass nouns, names for solid and nonsolid things, and names for categories organized by shape or material.

These studies demonstrate that the biases that develop are clearly influenced by the statistics of children's prior vocabulary learning, both in terms of 1) between-category organization and overlap between category organization, solidity, and syntax and 2) the specifics of the within-category variability children see. They also support the idea that what the child knows determines how they will be influenced by the regularities available to learn next. However, no work to date has examined in detail the relation between individual children's vocabulary structures and the biases they develop. This is the focus of the current paper. Specifically, we examine whether the statistics of individual children's vocabularies predict their individual likelihood to demonstrate a shape bias.

Noun generalization data are not typically analyzed at the level of individual children, because capturing detailed individual data can be difficult. One exception is a longitudinal study conducted by Gershkoff-Stowe and Smith (2004). They examined the vocabularies of individual children to find the point at which children first demonstrated a systematic bias to attend to shape in a novel noun generalization task. Gershkoff-Stowe and Smith found that as a group, children who knew more than 50 nouns showed a shape bias. Importantly, however, there was neither a "critical mass" of count nouns, or names for categories organized by similarity in shape nor a specific age or amount of time in the study that determined whether *individual* children demonstrated a shape bias in their task. In part this could be because only 1 novel noun generalization trial was collected from each child at each visit. Data from children this young are notoriously variable, thus it is possible that the patterns of individual children's

shape-biased performance with respect to their vocabulary structures were not statistically reliable, even if the group mean was. Clearly, multiple novel noun generalization trials are necessary to examine individual performance.

Another issue is what part of vocabulary to examine. Gershkoff-Stowe and Smith looked at the number of object names in productive vocabulary in relation to generalization biases. However, one could potentially examine classifications other than object names, and for that matter, break object names into other more fine-grained classifications as well. For example, some objects are solid things in categories organized by similarity in shape (e.g. ball) and some are nonsolid things in categories organized by material (e.g. pudding). Samuelson and Smith (using adult judgments of the nominal categories listed on the MCDI) examined the structure of the early noun vocabulary in terms of these other classifications. Adults were asked to judge whether each of the 312 nouns referred to a category of solid objects or nonsolid substances, a category organized by similarity in shape or material, and whether each noun was a count or mass noun. As can be seen in Figure 1, they found that there were more nouns referring to solid objects than nonsolid substances, more categories organized by similarity in shape than similarity in material, and more count nouns than mass nouns. Furthermore, there was more overlap between solidity, category organization, and syntax for the set of words that would support a shape bias—the “shape side” (solid+shape+count)—than between the set of words that would support a bias to attend to material when generalizing a name for a nonsolid—the “material side” (nonsolid+material+mass).

Using these judgments of the MCDI noun structure, Samuelson and Smith then examined both how the number of nouns of each type, and the number of nouns within a joint classification was related to the mean proportion shape responding in a novel noun generalization task. Looking at a wide range of children in terms of both age (17-33 months) and noun vocabulary size (0-309 words), they showed that

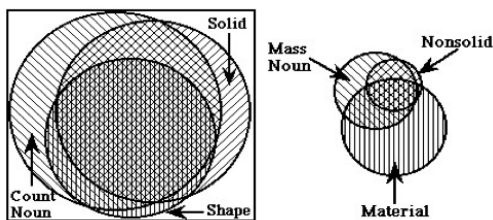


Figure 1: Overlap between solidity, syntax, and category organization based on Samuelson and Smith 1999 analysis.

children at all vocabulary levels had more names for solid objects, categories organized by similarity in shape, and count nouns than names for nonsolid things, categories organized by similarity in material, and mass nouns. However, only children with more than 151 nouns in their productive vocabularies demonstrated a shape bias. Thus, just because a child knows more words that fall into the classifications on the “shape side” does not mean that she

will demonstrate a shape bias—otherwise children in all the vocabulary groups would have demonstrated this bias.

Thus, to understand the relation between vocabulary structure and bias development we need to look at more than just the number of nouns of different types that children know. In particular, Samuelson & Smith’s data suggest that what may matter most for shape bias acquisition is the relative proportions of these kinds of words to other word types. In fact, despite the dominance of the shape side early in vocabulary development, there are also, of course, many other kinds of words that very young children learn. In terms of nouns, these other words include those that might support a bias to attend to material when a novel nonsolid substance is named, such as pudding and milk. In addition, children also learn nouns that are exceptions to the ontological divide. These words, such as pretzel (solid, + *material*) or bubble (nonsolid + *shape*), might be said to “go against the system” in that they would not support a link between solid objects and attention to shape or nonsolid substances and attention to material. In fact, given that all children will have many solid+shape+count words in their vocabularies, it might be more informative to look at differences across children in their knowledge of nouns that “go against the system.”

The nature of the MCDI also makes examination of these types of words critical. Samuelson & Smith chose to examine the MCDI in their study because it a reliable and valid measure with extensive normative testing (Fenson et al., 1994). However, Samuelson and Smith’s analysis tells us that this measure is itself biased towards count nouns that name solid things in categories well organized by similarity in shape. Accordingly, any child’s vocabulary measured with this tool will almost certainly have more of these kinds of nouns than others (as seen in Samuelson & Smith, 1999). Thus, with this measure we will only be able to detect relations between vocabulary structure and noun generalization performance if we look at the parts of the vocabulary that not all children share. One might argue that a measure other than the MCDI might be preferable. However, we choose to continue with this measure because 1) the MCDI is still the standard measure of vocabulary development for children the age-range we are interested in, 2) switching measures would necessitate obtaining new judgments of solidity, category structure and syntax, and 3) it enables comparison to prior work. In addition, because no examination of the statistical structure of the English language has been done, restricting the vocabulary of interest to the MCDI means we can examine our findings in the context of the known proportions of words on that measure. That is, we can look at the number of names for solid things in categories organized by similarity in material with respect to the known proportion of those kinds of words in the possible vocabulary we are examining. So while the MCDI might not be perfectly representative of all kids’ knowledge of all categories, it is useful in that it is the “average” vocabulary of an “average” child at a given age.

The goals of the present study, therefore, are to better

understand the development of word learning biases such as the shape bias by 1) exploring the structure of individual children's productive vocabularies with respect to individual and joint noun classifications, especially those words that go against the typical structure, and 2) using vocabulary structure to predict performance in novel noun generalization. We predict that the statistics of a child's vocabulary should be correlated with his or her performance in our task. Specifically, we expect to find differences in the words that individual children know, especially in those joint classifications that go against the typical structure (e.g. solids in material categories), that are linked to their likelihood of demonstrating a shape bias.

Method

Participants Seventy-five 15- to 23-month-old monolingual English speakers ($M=1$ year 7 months, 14 days) participated. There were 40 boys and 35 girls in the final group.

Stimuli Eighteen familiar objects and 30 novel objects were used. Familiar objects formed six sets of two identical objects and one completely different object (e.g. two identical blue cups and one yellow rabbit) used for a warm-up task. Novel objects were used in the novel noun generalization test. These formed six sets of five objects each. Each consisting of an exemplar object, two objects of the same shape as the exemplar but different in color and material (shape matches), and two objects made from the same material as the exemplar but different in color and shape (material matches). Six nonce words were used as names and were randomly assigned to each stimulus set and counterbalanced across participants.

Procedure Participants came to the laboratory for three experimental sessions spaced no more than eight days apart ($M: 3$ days, range: 1-8 days) (see Table 1). At each session the child completed four novel noun generalization (NNG) test trials for two of the novel sets so that after three sessions they had completed four trials for all six sets. Parents completed the MacArthur Communicative Developmental Inventory (MCDI): Words and Sentences (Fenson et al., 1994) at the first visit and reviewed it at each subsequent visit to add any new words the children began to produce over the course of the three visits to the laboratory.

On each trial the child explored the exemplar object, one shape match test object and one material match test object for about 10s. The experimenter then placed the two test objects on the tray, held up the exemplar saying, for example, "This is my kiv. Can you get your kiv?" and pushed the tray forward. Each of the two shape-match objects in a stimulus set were presented with each of the two material-match objects once for a total of four trials per stimulus set. After a child completed all four trials for a given stimulus set the experimenter moved on to the next set. The order of experimental trials within each stimulus set, as well as the order of the stimulus set was counterbalanced across children and across visits.

Coding & Analysis Sessions were videotaped and coded offline. 25% of sessions were recoded for reliability; inter-

coder agreement was 100%. All results are reported as proportion shape choice. We analyze NNG performance in two ways: 1) using t-tests against chance to examine overall performance and 2) using mixed logistic regression to examine the effects of vocabulary on performance.

We use mixed logistic regression because recent arguments suggest that ANOVA's on categorical outcome variables, such as those in a forced-choice NNG task, are inappropriate (see Jaeger, 2008). All analyses were conducted using the R language package. This approach has recently been used to demonstrate the links between the four steps of Smith et al.'s four-step process (Perry et al., 2010). Furthermore, these models are advantageous for our individual differences approach because we can include random subject and item effects in our models and thereby account for variance contributed by individual differences in children's vocabulary structure as well as differences caused by the particular stimuli. We removed collinearity from our models by sum-coding the data and scaling continuous variables. To determine appropriate random effects structure, we began with a completely specified random effects structure including random slopes for all variables included in a given model. Then, using model comparison, we systematically removed uninformative random effects to find an appropriate model (c.f. <http://hlplab.wordpress.com/2009/05/14/random-effect-structure/>). All final models included random intercepts for subject, items, and session.

Results and Discussion

We first examine the results of our NNG test. Specifically, we ask if participants show a significant tendency to select the shape match. Overall, children demonstrated a bias to choose the shape-match stimulus at test at greater than chance levels (.50), $M=.57$, $t(446)=5.81$, $p<.0001$. This suggests that, overall, children are biased to attend to shape when generalizing the names of novel objects. In addition, shape choices were significantly higher than chance for each of the three sessions, Session 1: $M=.59$, $t(75)=3.75$, $p<.001$, Session 2: $M=.58$, $t(75)=3.76$, $p<.001$; Session 3: $M=.55$, $t(74)$, $p<.05$. Thus, all children were attending to shape most when generalizing novel names for these solid objects

We next examine the relationship between vocabulary and NNG performance. We first overview participants' vocabulary structure in terms of single and joint classifications of solidity, syntax, and category organization. We then examine how knowing the names of words in each of these classifications influences the likelihood of demonstrating a shape bias. To begin our overview of vocabulary structure and to facilitate comparison to earlier work, we broke children into vocabulary subgroups based on the number of nouns in their productive vocabulary. We used the same groups as previously used by Samuelson & Smith (1999). These subgroups are as follows: 0-50 nouns, 51-150 nouns, 151-250 nouns, 251+ nouns. We examined NNG performance, the means and ranges of the total noun vocabulary, as well as the individual and joint classifications of the vocabulary for each subgroup. We also

measured the proportion of words in each noun classification out of the total number of nouns on the MCDI.

Overall, relative proportions of each of the single classifications are similar to that of the structure of the MCDI and that found by Samuelson and Smith (1999). For example, the proportion of count nouns/mass nouns for each subgroup (from lowest to highest) are .79/.10, .75/.11, .75/.10, and .75/.10 respectively, compared to .74/.10 of MCDI nouns. The proportions of joint classifications are also similar to the structure of the MCDI. For example, the proportion of nouns naming nonsolid substances in categories organized by material for each subgroup are .04, .02, and .02, compared to .02 of MCDI nouns.

Our overview of the vocabulary structure goes above and beyond the work of Samuelson and Smith (1999), however, in that we analyzed words that fall into joint classifications that go against the system, examining nouns that do not support the link between solidity, shape and count syntax or the link between nonsolidity, material and mass syntax. There are four such joint classifications of nouns on the MCDI. These include: names of solid objects that take mass syntax, such as “meat” (.006 of nouns); names of categories organized by similarity in shape that take mass syntax, such as “popcorn” (.003 of nouns); names of categories organized by similarity in material that take count syntax, such as “towel” (.006 of nouns); and names of solid objects in categories organized by similarity in material, such as “chalk” (.08 of nouns). There are clearly a considerable number of words that go against the development of a shape bias. In fact, there are actually twice as many names of solid objects in categories organized by similarity in material than there are mass nouns naming nonsolid substances, names of nonsolid substances in categories organized by material, and names of nonsolid substances in categories organized by material that take the mass syntax *combined* (.04 of nouns). The solid/material classification is also noteworthy for the relatively large standard deviations of each group. For example, the lowest vocabulary group has an average of .8 words in this classification with a range of 0-6, but the standard deviation is 1.3 words. There is more within-group variability in this classification than there is in the number of mass nouns or names for nonsolids those children know ($M: 1$, range: 0-4, $SD: .6$). Both this variability and the relatively large number of words that fall into this classification support further examination of the relationship between differences in individual children’s vocabulary structure and their novel noun generalization performance.

To examine the relationship between vocabulary and generalization, we first look at the NNG performance of each of the vocabulary subgroups. We scored responses such that a shape response received a 1 and material response received a 0. Thus the higher the score (out of the 24 possible trials), the more biased a participant was to attend to shape. All four groups were significantly likely to choose shape matches, 0-50: $M=.55$, $t(40)=3.68$, $p<.001$; 51-150: $M=.59$, $t(19)=4.11$, $p<.001$; 151-250: $M=.57$, $t(8)=2.80$, $p<.05$; 251: $M=.71$, $t(4)=2.82$, $p<.05$. However, it is also

apparent that not all individual children are choosing the shape match on every trial. In fact, only in the highest vocabulary group do all children have a score above 12 (corresponding to above-chance performance). On the other hand, children in the lower three vocabulary subgroups have a wider range of scores. This suggests that for the lower three vocabulary subgroups, despite overall high attention to shape, there are many children who are either performing at chance or demonstrating a material bias. In fact, a mixed logistic regression model accounting for random subject item, and session factors, shows that the three lowest-vocabulary groups are significantly less likely than the highest to generalize by shape, $z=2.55$, $p<.05$. We still need to know, however, if differences in the amount of shape responding relate to specific differences in vocabulary.

In order to examine differences in vocabulary, we must consider the possibility that such differences might not present themselves equally in each of our vocabulary subgroups. Because the MCDI has a fixed structure, knowing the majority of words on it will mean having a vocabulary that most closely conforms to that structure. Thus, those children with the largest vocabularies will have much less room to vary from the MCDI or from each other. Children with smaller vocabularies, however have more room to vary. As can be seen in Figure 2, the four vocabulary groups were not equally variable in NNG performance. This figure shows the proportion shape responding by vocabulary level for each child. Note that the lowest vocabulary group actually has some children that show a material bias, whereas all children in the highest vocabulary group show a shape bias. By including subgroup in our regression models, then, we can account for such variability and are actually able to better examine individual differences.

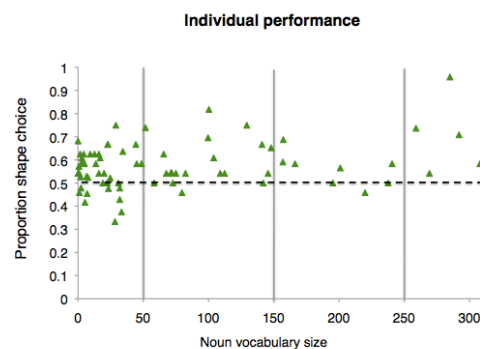


Figure 2: Noun vocabulary size and proportion shape choices for each individual participant.

Using mixed logistic regression, we examine the effects of the interaction between subgroup and each area of the vocabulary—shape side, material side and against the system—on shape choice in novel noun generalization. We do this by regressing out the number of total nouns a child knows from the number of nouns he or she knows within a given area, such that this predictor is the number of nouns a

child knows in a classification area above and beyond what would be predicted based on their group. Thus, the shape side predictor includes the number of count nouns that name solid objects, count nouns that name categories organized by similarity in shape, and the names of solid objects in categories organized by shape. The material side predictor includes the number of mass nouns that name nonsolid substances, mass nouns that name categories organized by similarity in material similarity, and the names of nonsolid substances in categories organized by similarity in material. The against the system predictor includes the number of count nouns that name categories organized by material, mass nouns that name solid objects, mass nouns that name categories organized by shape, and the names of solid objects in categories organized by material similarity.

We found that the number of words a child knows on the shape side was a significant predictor of novel noun generalization performance such that knowing more of these words leads to a bias to attend to shape, $z=2.19$, $p<.05$. There is also a significant interaction such that children with smaller vocabularies who know more of these words are more likely to attend to shape, $z=2.56$, $p<.05$. The model also shows that the number of words a child knows that go against the system is a significant negative predictor of novel noun generalization such that knowing more of these words leads to a bias to attend to material, $z= -2.22$, $p<.05$. There is also a significant interaction such that children with smaller vocabularies who know more these words are more likely to attend to material, $z= -2.56$, $p<.05$. There was no effect of the number of words a child knows on the material side, however, $z= -.62$, ns.

We next conducted model comparison to examine which of these predictors was necessary to account for children's performance in novel noun generalization. We found that a model without either the shape side predictor or the against the system predictor were significantly worse than a model that contained all three predictors, $X^2(1)=11.28$, $p<.05$, and $X^2(1)=13.78$, $p<.01$, but a model without the material predictor was not statistically different, $X= .64$, ns. Further model comparison revealed that a model containing only the shape side predictor was significantly worse than a model with all three predictors, $X^2(1)=16.78$, $p<.05$. A model containing only the against the system predictor, however, was no different than the model with all three predictors, $X^2(1)=11.85$, ns. Thus, the number of words children know that go against the system can account for their novel noun generalization performance.

To understand what this result means we next consider the composition of classifications of nouns that go against the system. There are 31 nouns in classifications that go against the system. However, 25 of these name solid objects in categories organized by material, while the other 6 are spread across four other classifications: 2 count nouns that name material categories, 2 mass nouns that name solid objects, 1 mass noun that names a category organized by shape and material, and 1 count noun that names a category organized by shape and material. Furthermore, there was

only one child in the smallest vocabulary group who knew a word from each of these other classifications. Clearly, most of the work of the against the system predictor is being done by the number of names of solid objects in material categories children know. In fact, a model of just the interaction between vocabulary group and the number of nouns a child knows that name solid objects in categories organized by similarity in material was able to account for children's novel noun generalization. The more of these words children know, the more likely they are to demonstrate a material bias, $z= -2.21$, $p<.05$. Furthermore, there was an interaction such that children with smaller vocabularies who knew more of these words were more likely to demonstrate a material bias, $z= -2.48$, $p<.05$. This result is pictured in Figure 3. The negative slope of the red line is the clearest illustration of the finding that number of names of solid objects in material categories children know above and beyond what we would expect given their vocabulary group predicts their likelihood of demonstrating a shape bias, but the negative slope is also clear for the 51-150 and 151-250 vocabulary groups as well.

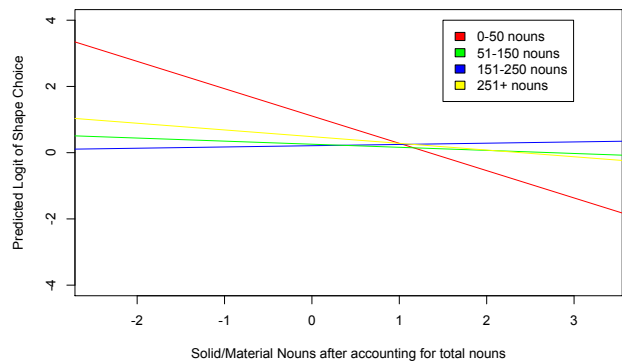


Figure 3: Relationship between number of names of solid objects in material categories a child knows above and beyond what we would expect given their vocabulary group and likelihood of choosing shape match.

Overall, our results suggest that the structure of a child's vocabulary can predict the direction of attentional bias she will demonstrate in an NNG task with solid objects. A vocabulary dominated by the overlap between solid objects and shape organization will support attention to shape when the child is asked to generalize the names of novel solid objects. However, as can be seen in Figure 3, if the structure of a child's vocabulary is dominated by the overlap between solid objects and *material* organization, then this will support attention to material. Thus, the individual biases children demonstrate are tightly linked to the specifics of their individual vocabularies.

General Discussion

Importantly, this is the first in depth look at individual children's vocabulary and its effect on word learning biases. This study is also the first to examine how words that

“against the system” affect the biases that emerge. In doing so, we were able to demonstrate that knowing more words that name solid objects in categories organized by material leads to a bias to attend to material when generalizing the names of novel solid objects. Interestingly, attending to material in naming solids is actually not inappropriate when we consider that as adults we have to be able to flexibly shift to attend to any number of dimensions depending on context. For example, we are clearly able to have multiple construals for solids (e.g. considering a table either as a table (shape construal) or as made of wood (material construal)) (Prasada, Ferenz, & Haskell, 2002). In fact, the four-step process predicts that there is nothing special about the shape side of the vocabulary per se, but rather its dominance and the overlap between these classifications are what lead to the emergence of the shape bias. The reason, then, that a bias to attend to shape seems to become the default early on is because of this default structure in the English noun environment. This makes our study one of the strongest tests of the four-step process, because we are able to demonstrate that when children have noun environment (e.g. their individual vocabulary) with a different structure than the typical one, they show different, and related biases.

Acknowledgments

Research was supported by grant R01 HD045713 awarded to Larissa Samuelson by the National Institutes of Health.

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