# Measuring the development of the shape bias in early word learning across methodological variations

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## Abstract

Young children often generalize word meanings based on object shape, yet the mechanisms driving shape bias and its variability remain poorly understood. Theoretical debates about the origins of shape bias and whether it is rooted in syntactic structure, statistical regularities, or conceptual representations underscore the need for a unified method, since evidence from different methods often leads to conflicting evidence. Here, we explore methodological factors contributing to heterogeneity in shape bias studies, including task format, stimuli design, and theoretical frameworks. Through a series of experiments, we systematically manipulated object properties—shape, material, function, and affordances—and examined their effects on children's generalization patterns. Preliminary findings indicate a robust preference for generalizing by shape, even when function is made salient, suggesting that children may prioritize shape as a proxy for category membership. However, possible nuanced interactions between stimuli design, task structure, and prior experiences in the environment highlight the role of context and task dependency in influencing behavior. Unified methodologies are needed to reconcile conflicting evidence and resolve cross-linguistic and theoretical debates about the origins of the shape bias.

**Keywords:** word learning; language acquisition; shape bias; heterogeneity; method variation; stimuli variation

What does "dog" mean to a 2-year-old? This old question reflects the evolving nature of our understanding of early label categorization. For young children, a dog might initially be identified by a set of general features that expands with experience i.e. the features that children rely on to organize their label categories (Waxman & Markow, 1995). For example, the semantic features hypothesis (Clark, 1973) suggests that categorization begins with a schema of basic perceptual attributes, such as [four legs, tail, fur] for dog, hence we see over-extensions of the word "dog" to beings that share these set of features like cats for example. Over time, deeper attributes, such as its internal composition, behavior and interaction with the world, or sound, may also become relevant. In contrast, the functional core hypothesis (Nelson, 1974) posits that children extract relationships among features to identify future category members without treating these features as defining. In this view, invariant perceptual attributes like [four legs, tail, fur] act as identifiers rather than encapsulating the category's essence. Both frameworks agree, however, that shared perceptual features facilitate identification and labeling, forming the foundation for the well-studied shape bias (Baldwin, 1992; Graham & Diesendruck, 2010; Graham & Poulin-Dubois, 1999; Imai et al., 1994; Landau et al., 1988; Samuelson & Smith, 2000).

The *shape bias* is the tendency to generalize objects names by their shape (i.e. What does "hammer" mean to a toddler? One possibility is that "hammer" refers to other hammer-shaped objects), rather than other properties like the material it is made from, or its color. The presence of a shape bias is argued to facilitate early noun acquisition, to be an important route to vocabulary growth, and to be weaker in children with language delay (Jones, 2003; Jones & Smith, 2005; Smith et al., 2002; Tek et al., 2008; Tek & Naigles, 2017). The shape bias is typically measured using word extension tasks, in which children are taught a novel label for an object and then tested on their ability to extend it to other objects (Waxman & Markow, 1995). Yet although the shape bias is found robustly in such tasks, there is still substantial variation in when, and at what magnitude, the shape bias is detected (Abdelrahim & Frank, 2024; Kucker et al., 2019). This variation plays a key role in differentiating between theoretical accounts of the origins of this bias.

One possibility is that the shape bias is a universal constraint on generalization (Markson & Bloom, 1997; Soja et al., 1991), such that all toddlers will show a shape bias in generalization contexts including non-linguistic contexts, regardless of their language or environment. However, robust evidence suggests cross-cultural variation, casting doubt on this explanation. For example, speakers of East Asian languages like Mandarin and Japanese demonstrate less reliance on shape when extending nouns compared to English speakers in the United States (Gathercole & Min, 1997; Imai & Gentner, 1997; Samuelson & Smith, 1999; Smith et al., 2003; Soja et al., 1991; Subrahmanyam & Chen, 2006; Yoshida & Smith, 2003b). Two key hypotheses attempt to explain these differences. First, differences in linguistic structure, such as count-mass syntax in English versus classifier systems in East Asian languages, might influence the prevalence of the shape bias (Imai & Gentner, 1997; Samuelson et al., 2008; Soja et al., 1991; Soja et al., 1992). Second, variations in lexical and environmental statistical regularities tunes attention toward features like shape. This hypothesis emphasizes the role of existing vocabulary and environmental exposure in guiding category organization (Colunga & Smith, 2000; Gershkoff-Stowe & Smith, 2004; Jara-Ettinger et al., 2022; Perry et al., 2010; Samuelson, 2002, 2005; Samuelson & Smith, 1999; Yoshida & Smith, 2003a).

A second key question is the mechanism or representa-

tion underlying the shape bias. While the tendency to extend nouns based on shape may be influenced by syntax or statistical regularities, its precise cognitive basis has been controversial (A. Booth & Waxman, 2006; Bruner, 1964; Jones & Smith, 1993; Samuelson & Perone, 2010; L. Samuelson & Horst, 2008; Smith et al., 1996, 2002, 2010; Ware & Booth, 2010). Two competing perspectives attempt to explain this mechanism. One possibility is that the shape bias is an associative (non-strategic) mechanism, driven by perceptual features that guide children to perceptual attributes associated with category labels (Smith et al., 1996, 2002, 2010). Alternatively, the shape bias may be a strategic and conceptually-controlled mechanism, governed by general world knowledge and conceptual understanding (A. Booth et al., 2005; A. E. Booth & Waxman, 2002). In this view, the bias is a heuristic whose magnitude might vary when the context of the generalization requires the child to attend to other features, such as the object's function or material. For example, children might initially categorize an object as a stone based on its shape, but if the object is made of sponge rather than rock, the importance of material may override the reliance on shape. In this case, children may recognize that being made of rock is a defining feature of the category, leading them to prioritize material over perceptual similarity.

Thus, variability in the shape bias is a key source of constraint on theories of its origins. However, the sources of this variability remain unclear. A recent study used statistical meta-analysis to estimate the effect size of the shape bias across 40 studies, finding a large average effect (0.8 standard deviations) (Abdelrahim & Frank, 2024). However, effects varied widely across seemingly similar studies, and the vast majority of the variance in the data remained unexplained by moderators such as age or language. One possibility is that methodological differences across studies contribute to the observed variation. For example, task format, stimuli design, and participant characteristics might influence the magnitude of the shape bias. In this paper, we explore the role of methodological factors in shaping the shape bias, using a series of experiments that systematically manipulate object properties and examine their effects on children's generalization.

Word extension studies typically teach children a novel label for a novel object, and then test them on the ability to extend it to other objects that share features like shape, or material with the target object. But these tasks vary in their dependent measure and their stimuli. With respect to dependent measures, children are typically either asked to make a forced choice between possible extensions, requiring a choice of the best generalization, or are asked to perform yes/no endorsement of different possible extensions, allowing multiple exemplars to be judged similar to the target (Landau et al., 1988). Some paradigms also allow children to reject all options. It is not yet clear how different tasks affect performance. For example, allowing children to select "none of those" reduces shape bias, especially with complex objects (Cimpian & Markman, 2005).



| Exemplar | Shape match | Function match | Function (fx) | fx involves: |
|---|---|---|---|---|
| | | | holds toys | whole structure |
| | | | scoops sand | part of the structure |
| | | | makes a heart | part of the structure |
| | | | holds water | reasoning about material |
| | | | grabs toys | reasoning about material |
| | | | moves [handles] | Part of the structure |
| | | | makes a squeaky noise | reasoning about material |

Figure 1: Examples of stimuli objects used in both experiments

The second major methodological variation in the word extension findings comes from differences in stimuli. The key dimension of variation is the alternative possible dimensions of generalization beyond shape. Some studies contrast shape and other perceptual features, such as color or material, using stimuli designed to highlight these attributes. On the other hand, studies investigating conceptual understanding often include cues related to animacy, such as eyes, shoes, or other salient features, and use test objects that share multiple dimensions with the exemplar instead of only one (Jones & Smith, 1998; Yoshida & Smith, 2003b). When functionality is emphasized, stimuli are often paired with demonstrations of an affordance, stories, or narratives to contrast shape with function. Children aged 2 to 5 years are found to prioritize shape, even when provided with functional information (Centner, 2003; Graham et al., 1999; Landau & Jones, 1998; Merriman et al., 1993). However, conflicting evidence shows children sometimes prioritize function or other cues (Gelman & Medin, 1993; Kemler Nelson & 11 Swarthmore College Students, 1995). In addition, some studies use pictures or drawings, while others use physical objects.

Our goal in the current study is to evaluate procedural sources of variability as part of a larger scale assessment of word generalization across age groups and languages. We used a within-subject design to maximize precision in esti-

mating condition differences. We also aim to measure developmental change by recruiting a sample size large enough to estimate age-related change. In Experiment 1, we began by measuring developmental change in the shpae bias. In Experiment 2, we manipulated the presence of alternative generalization items that shared function but not shape with the target object. Across both studies, we observed a robust shape bias that increased with age; preliminary data from Experiment 2 yielded no evidence that function information reduced the shape bias.

## Experiment 1

### Methods

**Participants**  Twenty four typically developing English speaking participants (2-5 years old, mean=3.79, SD=1.28) were recruited from a local nursery school and children's museum in the US ( `https://aspredicted.org/ncwz-pmtz .pdf`).

**Materials**  To investigate children's reasoning about objects' properties and functions, a series of object sets were designed, each containing one exemplar, a material match, a shape match, a function match, and a distractor (e.g., dax, fep, blicket, gorp, zimbo, wap, blint). These sets allowed for systematic manipulation of object features to assess various cognitive processes related to word learning and category generalization. Example objects are shown in Figure 1. In Experiment 1, the shape match was contrasted with a material match. This served as a baseline check and replication of prior findings regarding shape bias in categorization tasks. In Experiment 2, the same exemplar was used, but the shape match was contrasted with a function match.

The function test object was modified in a way that preserved its shape but altered its functionality (e.g., an object wrapped entirely vs. one that could clearly open). Color was different across all objects to ensure that visual similarity was driven solely by shape, material, and functional cues. Objects were crafted to explore how children reason about similarity based on whole-object vs. part-based features (e.g., whether specific parts afford a particular function). Some objects, such as the "fep," "blint," and "wap," were designed with material-critical functions (e.g., holding water while made of a paper towel). This design tested whether children could prioritize material when reasoning about function and to capture the developmental changes. The degree to which an object's affordances were visually apparent varied across designs. For example, the "zimbo" was designed to afford functionality only through a specific part, while the overall structure was irrelevant. The "gorp" was modeled to resemble objects familiar to slightly older children, like scissors, allowing exploration of prior experiences' influence on categorization (see supplementary `https://osf.io/rngqa/ ?view_only=f0ac61b08e71404b814f5355e128c2df`).

**Procedure**  On each trial, the child was shown an object, which was labeled with the phrase "this is a [X], do you see
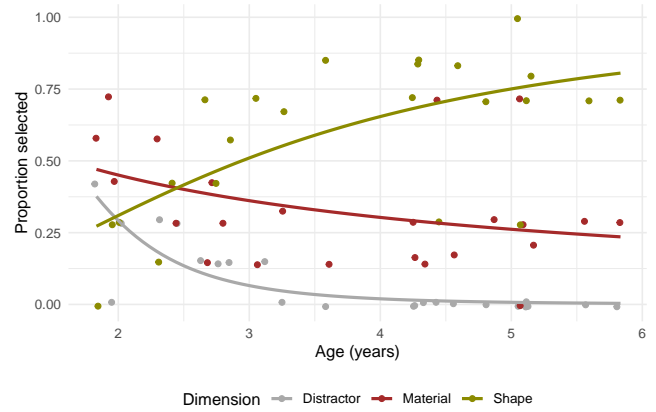


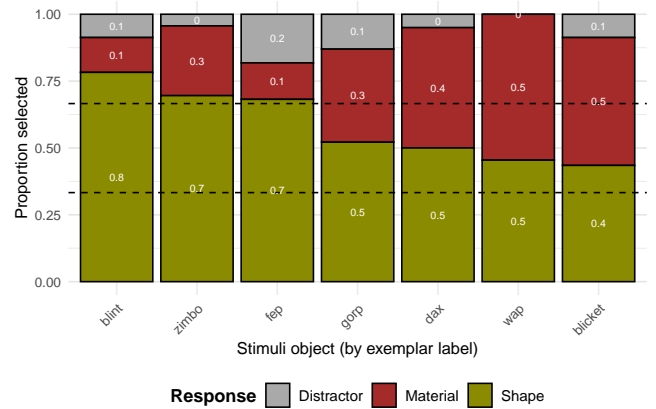Figure 2: Developmental trend of choosing by each dimension.



Figure 3: Percentage of choosing by dimension per stimuli item, indicated by its novel label (aggregate across participants). Dashed line is chance level = 33.3%

the [X]?". The object was moved away from the child but remained in view, and both the test object and the distractor were displayed simultaneously while asking the child "can you find another [X] by pointing to it?". The child gets to hear the label 3 times while viewing it without touching it. Each child saw seven trials.

### Results

Participants showed an overall shape bias across all trials (shape: 61%, material: 30%, distractor: 9%). Figure 2 shows a developmental shift to choose by shape by age 3, replicating what is seen previously in the literature.

To quantify these trends, we fit a generalized logistic mixed effects model predicting the binary outcome of choosing by shape for each trial by each child. We included random intercepts at the level of both participants and stimuli objects. The average intercept odds of choosing by shape were 1.5 (odds of 1.5:1 at the mean age, $\hat{\beta} = 0.40$, 95% CI $[-0.13, 0.94]$, $z = 1.49$, $p = .136$), with a significant increase in odds of 1.05

per month increase in age ($\hat{\beta} = 0.05$, 95% CI $[0.02, 0.08]$, $z = 3.32$, $p < .001$). The model also shows variability at the item-level intercept ($SD = 0.43$) across 7 unique items.

## Discussion

Even in a small sample of children between 2 and 5 years of age, data from this experiment confirmed the robustness of the shape bias. Although it is not clear why children below age 3 chose more by material, there was variability at the item level such that for three objects we saw above chance material choices when collapsing across ages.

## Experiment 2

After replicating the shape bias effect using our stimulus set, our next experiment explores the role of functional explanations in moderating the shape bias. We compared two conditions: first, where shape is only contrasted with material without any additional information; second, where shape is contrasted with function after demonstrating the function for the exemplar. We also substantially increased our planned sample size for this study. The results from the experiment is preliminary and data collection is still ongoing.

## Methods

**Participants**   31 (target n=96, 24 per each age group) participants between 2-5 years old (mean=48.23, SD=5.6) were recruited from a local nursery school in the US (`https://aspredicted.org/yqqb-sn52.pdf`).

**Procedure**   A within subject manipulation with two conditions: material or function. The material condition is identical to the first experiment. In the function condition, the experimenter introduces the exemplar object, let the child play with it for 15 seconds, introduces the object label ("this is a [X]), provides functional information ("the [X] grabs toys"), gives another 15 seconds to play with it, and puts the toy away within the child's view. They then introduce the test objects as in Experiment 1 and ask for a response. The order of conditions was counterbalanced.

## Preliminary results and discussion

Figure 4 shows results from ongoing data collection. A generalized logistic mixed-effects model (GLMM) showed non-significantly lower baseline odds of the shape bias in the material condition compared to the function condition ($\hat{\beta} = 3.29$, 95% CI $[-2.46, 9.03]$, $z = 1.12$, $p = .262$). Random effects indicated variability in intercepts across participants (SD= 0.14) and across items (SD= 1.39) for 31 participants and 7 items (Figure 5).

In the function condition, many children attempted to explore whether their chosen test object could perform the intended function after selecting it based on shape. This behavior suggests that shape-based selection does not necessarily indicate a disregard for functional information but may instead reflect a hypothesis that objects sharing the same shape might also share functionality. For example, in the case of the

dax—a box with a lid used for storing small toys—children often selected another box that was completely wrapped shut, preventing it from being opened, yet still attempted to open it. Additionally, the proportions of shape-based and function-based choices were relatively comparable, indicating that children were not exclusively relying on one dimension when making their selections.

In the case of the "zimbo," it may seem that children in both conditions did not choose based on shape. However, a small embedded part (a heart-shaped feature) was shared between the exemplar and both the material and function test matches, potentially influencing their selections. For the "gorp," where the function was less ambiguous (scooping sand requires an object to have two parts that split and then close to hold sand inside), children were more likely to select the functionally appropriate object. This effect was particularly pronounced when the test object was designed in a way that made it visually clear that it could not open, suggesting that functional information guided their choices more effectively in such cases.

Children's ability to reason about intrinsic affordances—specifically, what a material enables or restricts—remains ambiguous. For instance, in the case of the "fep," an object designed to hold water but made of a paper towel, children chose based on shape twice as often as function. This suggests that, at least in some cases, material constraints may not be a primary factor in their reasoning.

These findings highlight the complex interplay between shape, function, and material, revealing instances where these dimensions are confounded. Further data collection and analysis will be necessary to disentangle these relationships and determine the extent to which each factor influences children's categorization and generalization behavior.

## General Discussion

The category organization and word extension literature is highly heterogeneous, which hinders our ability to draw consistent conclusions. To achieve more accurate measurements of category organization and concept learning, we need a reliable and valid set of stimulus objects, consistent task formats, and standardized test designs. Additionally, multi-site, cross-cultural experiments, unified across laboratories, are essential to account for variability as comprehensively as possible.

As we mentioned in the introduction, procedural variations observed in the literature have followed theoretical debates and, in many cases, have been reinforced by them. We view our approach as a step toward improving the validity and reliability of word extension tasks while also addressing the theoretical implications of these variations (Madole & Oakes, 1999). For instance, the definition of the shape bias as a word extension strategy remains ambiguous and is influenced by theoretical framing. If the shape bias emerges from contingencies and statistical regularities in the input, then from a signal detection perspective, it would be reasonable to predict that its strength varies in a graded manner across populations, individuals, and items. However, analyzing data solely at an aggregate level across these dimensions has not meaningfully
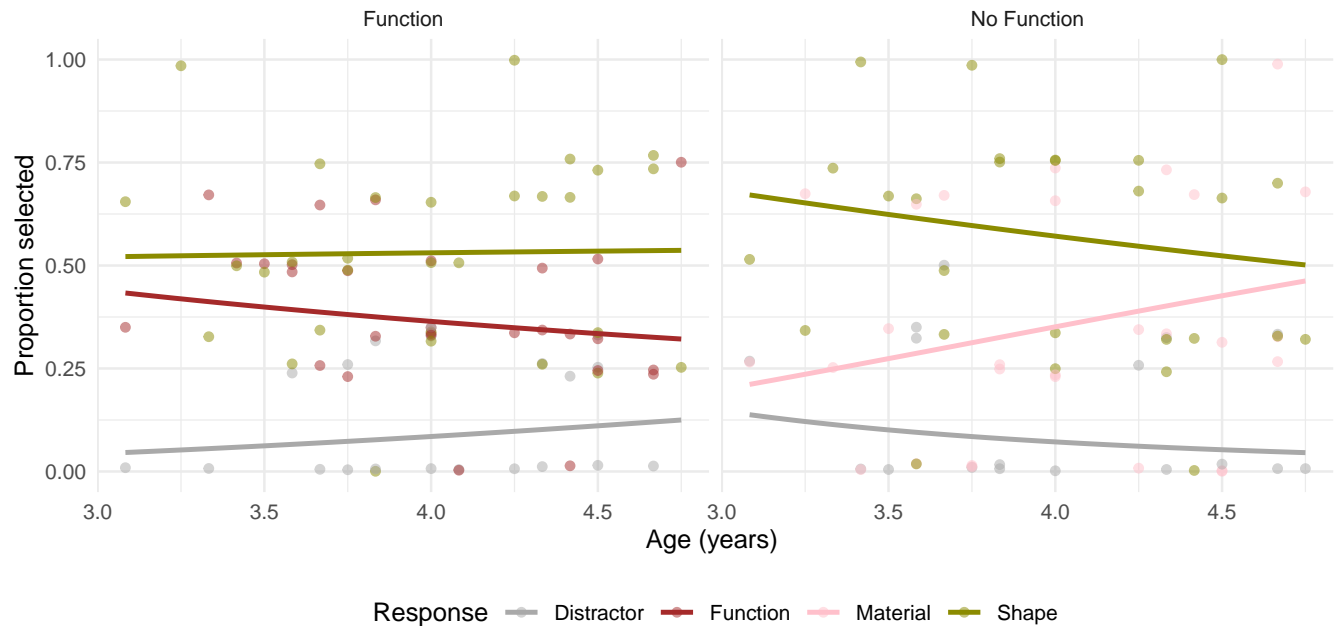
Figure 4: Experiment 2, function vs. no function condition. Distractor is no match at all. Data points are individual participants. Children choose by shape more, even when function information is made salient.
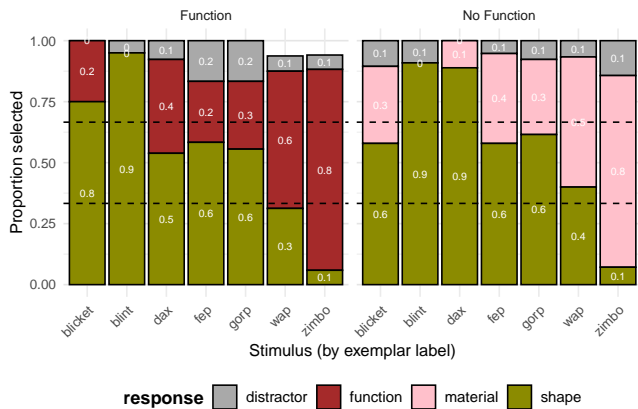


Figure 5: Experiment 2, proportion of choosing by each dimension per exemplar item, indicated by its novel label(aggregate across participants). Dashed line is chance level = 33.3%. We note variability across items.

advanced our understanding of cross-cultural differences.

Our evaluation of the word extension literature suggests that procedural decisions—likely a primary source of unexplained variability—cannot be properly assessed without conducting a series of controlled experiments. These experiments would allow us to systematically examine how different designs and stimuli covary with response patterns, ultimately enabling a more precise understanding of how methodological factors influence children's word generalization. Our work here is a very first step towards that goal.

Our preliminary results indicate a strong tendency to generalize by shape, even in conditions specifically designed to make function salient. This suggests that even when functional information is highlighted, it often fails to override children's preference for shape-based choices. However, children's post-selection exploration of the shape-matching object (e.g., attempting to open the dax) indicates an understanding of the intertwined relationship between object identification, recognition, and conceptual representation.

To evaluate children's ability to reason about intrinsic affordances, we included the "fep" object, an object where material properties were critical for performing its function—holding water while being made of a paper towel. This design allowed us to assess whether children recognized material constraints as an essential factor in determining functionality. We believe that structural differences between objects, such as these, contribute significantly to variation in children's responses. With a sufficiently large dataset, we expect to capture these influences more precisely in our statistical models.

A more quantifiable assessment of word generalization—one that systematically accounts for variation across items, individuals, and cultures—will be essential for resolving these issues. By building a robust methodological framework and integrating findings across diverse contexts, we aim to move toward a more coherent understanding of how children generalize words and organize categories across different languages and developmental environments.

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