Knowledge, Performance, and Task: Décalage and Dynamics in Young Children's Noun Generalizations

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Abstract

Studies of cognitive development often find that children's abilities shift across age and task. The present paper examines an example of such developmental décalage: the same pattern of performance in novel noun generalization occurring at two points in development across forced choice and yes/no tasks. A formal model of these tasks, and an experiment directly comparing performance of children at the same developmental level in each task, demonstrate the importance of understanding how knowledge interacts with the specifics of the task to create behavior and development.

Introduction

The cognitive development literature contains numerous studies that have attempted to examine whether children at a particular age possesses some knowledge only to find that children's abilities shift across ages and tasks. This results in cases where older children do not seem to be able to do something that younger children do. For example, studies with young infants suggest that three and four-month-old children can use knowledge of physical laws of continuity and solidity to determine where a ball rolled down a ramp should stop (Spelke, Breinlinger, Macomber, & Jacobson, 1992). Yet, when tested in similar paradigms, 2- and 3-year-old children do not seem to have this same knowledge (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000). Similarly, research has suggested that 6- to 8-month-old infants can detect the numerical equivalence between sets of auditory and visual stimuli (Starkey, S., & Gelman, 1990). Yet, 3-year-old children fail at a similar task (Mix, Huttenlocher, & Levine, 1996). Such examples leave the field in a difficult position: how are we to know when a child possesses some bit of knowledge?

We argue that this is the wrong question because it focuses on knowledge as something that can be had. Rather, we suggest that knowledge should be viewed as something that is created in a moment, out of the interaction of the child's previous history of perceiving and acting and the current task. From this perspective, the question to be asked is how the specifics of the task bring the child's prior history of perceiving and acting to bear in the moment. We illustrate the utility of this perspective by examining a "case study": the same pattern of performance in novel noun generalization occurring at two points in development across two different tasks—an example of what Piaget referred to as décalage (Piaget, 1952). We will show how a close examination of the interaction of the child in the task via a computational model furthers our understanding of the processes that underlie early word learning in young children. This sets the stage for future work that integrates the real-time dynamics of children's response generation with an understanding of the development of children's word learning and categorization abilities.

Naming Deformable Things

A young child shown a novel solid object and told a novel name (e.g. "this is a dax") will most likely say that only other objects that share the same shape as the exemplar can be called by the same name (Landau, Smith, & Jones, 1988). Thus, young children are said to show a "shape bias" when generalizing novel names for solid objects. There is some debate in the literature concerning the nature and origin of the shape bias. Nevertheless, recent studies suggest that children who learn to attend to shape when naming novel objects subsequently show accelerated vocabulary development (Samuelson, 2002; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002) and that development of a shape bias is related to the development of the early noun vocabulary (Gershkoff-Stowe & Smith, 2004; Samuelson & Smith, 1999).

A bias to attend to shape, although useful for learning nouns such as table, hammer and key that name solid objects in shape-based categories (Samuelson & Smith, 1999), may not be appropriate for all nominal categories, however. For instance, it is not clear that children should attend to shape when naming things made from deformable materials such as paper, blankets and towels because, while these typically have characteristic shapes, they are organized into categories based on similarity of material (Samuelson & Smith, 1999, 2000), and material substance is often critical to what can be done with these things. Thus, in Experiment 1 we examined how young children generalize names for deformable stimuli. In particular, we recruited children in the early stages of productive vocabulary

development (c.f. Gershkoff-Stowe & Smith, 2004; Samuelson & Smith, 1999), and asked them to make generalizations following demonstrations that highlighted the deformable nature of the exemplar. Children were also asked to generalize novel names for rigid stimuli under similar conditions.

Experiment 1

Methods

Participants Fifty-nine monolingual, English-speaking children, 31 girls and 28 boys, (range = 18m 12d – 23m 23d, *M* = 21m 8d) were recruited from county birth records.

Stimuli Four sets of novel objects, each with an exemplar and four test objects, were used. The exemplars were made from sponge, plastic bean bag, wood and Styrofoam. For each set, two of the test objects were the same shape as the exemplar but were different colors and made from different materials, and two were made from the same material as the exemplar but were different shapes and colors.

Task The experiment began with a series of training trials to familiarize the child with the forced choice task. On each trial the child was shown a plastic egg, which was named, and shown that the egg could open. The experimenter then placed two test objects—a second egg identical to the named exemplar, and another object that differed from the egg in shape, color and material—on a tray and asked, "Can you get another egg?" while sliding the tray towards the child. Children were praised if they chose the egg and corrected otherwise.

The experimental trials proceeded in the same manner as the training trials, with the exception that the child's responses were neither praised nor corrected. Thus, for each trial the experimenter named the exemplar and demonstrated a property designed to highlight the shape of the rigid exemplars and the material of the deformable exemplars (e.g. rolling for a rigid exemplar, and squishing for a deformable exemplar). Two test objects were then placed on the tray, and the tray slid forward while the experimenter asked the child "Can you get the (novel name)?" Within each set, each shape match was presented once with each material match for a total of four trials. Children's choices were coded offline from videotape by coders blind to the experimental hypotheses. Twenty-five percent of the sessions were coded by two coders. Agreement between coders was 94%. Disagreements were resolved by review of the videotapes.

Results

Children were divided into three groups based on the number of count nouns in their productive vocabulary; 0–25, 26-50, 51+ count nouns. These divisions were based on natural breaks in the data that yielded approximately equal numbers of children in each group (17, 23, and 19 respectively).

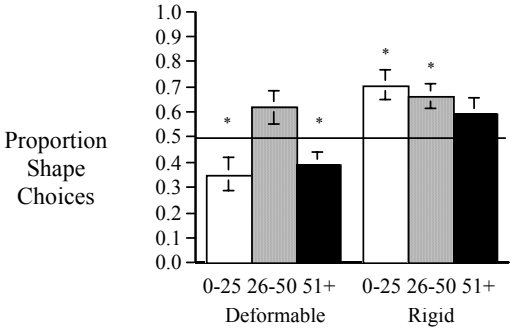

Figure 1: Data from Experiment 1. Proportion of shape choices for children at each vocabulary level for sets with deformable and rigid exemplars. * denotes performance different from chance at $p < .05$ level

As can be seen in Figure 1, noun generalizations were influenced by the rigidity of the exemplar and the vocabulary level of the children. Across these vocabulary levels, children tended to generalize novel names for rigid exemplars to test objects that were the same shape. In contrast, children with very few (0-25), or very many (51+) count nouns in their productive vocabulary generalized novel names for deformable exemplars to test objects made of the same material, while children with 26-50 count nouns in their productive vocabulary, were more likely to generalize names for deformable exemplars to test objects that matched the exemplar in shape.

Discussion

The finding of a relationship between the properties of the productive vocabulary and children's behavior when generalizing novel nouns is consistent with previous work (Gershkoff-Stowe & Smith, 2004; Samuelson & Smith, 1999). However, the reduction in the strength of the shape bias from the middle to high vocabulary group contrasts with previous results suggesting that the shape bias increases in strength until 3 years of age (Jones & Smith, 1993). Further, the fact that the 18- 23 month-old children with the most count nouns in their productive vocabularies did not attend to shape when generalizing novel names for deformable stimuli, is in opposition to a previous finding by Samuelson and Smith (2000). These researchers found that 36-month-old children generalized novel names for deformable stimuli by shape. It seems very likely that the much older 36-month-old children in that study would have had many more count nouns in their productive vocabularies compared to the young children tested here. One difference between Experiment 1 and Samuelson and Smith's work, however, is that we used a forced choice procedure, whereas Samuelson and Smith used a yes/no procedure. Thus, in Experiment 2 we used the same stimuli to examine the noun generalizations of a group of children at the high vocabulary level from Experiment 1 in a yes/no task. We also ran a group of 36-month-old children in order to replicate Samuelson and Smith's prior finding, and a group of 48-month-old children to examine whether attention to shape is also modulated later in development in the yes/no task.

Experiment 2

Methods

Participants Sixteen 2-year-old children (range = 23m 25d – 27m 5d *M* = 25d 19m), 16 3-year-old children (range 36m 20d – 38m 28d, *M* = 37m 12d), and 16 4-year-old children (range = 48m 5d – 49m 18d, *M* = 48m 27d) were recruited from the same population as Experiment 1. All children were learning English as their first and only language, and none had participated in Experiment 1.

Stimuli In order to replicate the procedure used by Samuelson and Smith (2000), two test objects that matched the exemplar in color were added to each stimulus set. In all other respects the stimuli were identical to those used in the previous experiment.

Task As in Experiment 1, **t**he experiment began with training trials. These were used to familiarize the child with the yes/no procedure. On the first training trial the child was shown a plastic egg. The experimenter demonstrated that it opened and then brought out a series of test objects one at a time and, for each, asked "Is this an egg?" The test objects included two plastic eggs identical to the exemplar and several other small objects that were all different from the egg in shape, color and material. During training the experimenter praised the child for correct responses and corrected incorrect responses. The experimental trials proceeded in the same manner as the training trials with the exception that the experimenter did not praise or correct the child. For each set, the six test objects were presented one time in one of two random orders. The order of sets was counterbalanced across children.

Results

As can be seen in Figure 2, there were differences in children's tendency to attend to shape across age and exemplar. Overall, the data from the 36-month-old children replicate Samuelson & Smith's (2000) previous finding—these children generalized novel names for both rigid and deformable stimuli by similarity in shape. In contrast, both the 24- and 48-month-old children generalized names for deformable stimuli in different ways than they generalized names for rigid stimuli. Specifically, both these groups of children generalized names for rigid exemplars by shape but were equally likely to generalize a name for a deformable exemplar to shape-or material-matching test objects.

Discussion

The data from Experiment 2 seem to conflict with those from Experiment 1. How is it that we can see the same curvilinear trend in children's naming of deformable stimuli in a group of 18-to 23-month-old children with different numbers of count nouns in their productive vocabularies, as we see with 24-, 36-, and 48-month-old children using the same stimuli? Clearly, there are important differences in the word learning and categorization abilities of children across these age ranges. Nevertheless, what may be critical in understanding this developmental décalage is how the specifics of the task bring these developmental differences to bear and create behavior in a moment in time.

In particular, there are two critical differences between the forced choice task used in Experiment 1 and the yes/no task used in Experiment 2. First, in the forced choice task, children see the two test objects at the same time in close proximity (i.e. on the same tray). In contrast, in the yes/no version of the task, children see the test objects one at a time. Thus, children can make direct comparisons between the test objects in the forced choice task, but must make these comparisons in memory (if at all) in the yes/no version of the task. Second, the nature of the forced choice task is to force the child to pick one object to the exclusion of the other. In contrast, in the yes/no version of the task, the child is free to say yes (or no) to all of the test items individually.

These differences have important implications for how a child's prior history of perceiving and acting are brought to bear in a moment in time. For example, a relatively small bias to attend to shape may appear larger when children are forced to pick between a test object that matches an exemplar in shape and one that matches it in material. Likewise, a relatively weak bias to attend to material with deformable stimuli may be more apparent in a yes/no task

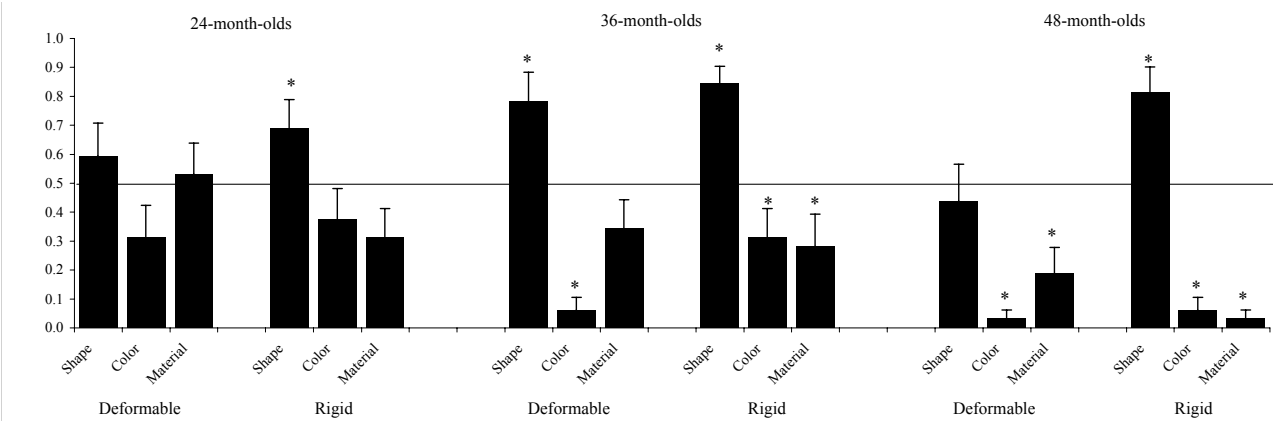

Figure 2. Data from Experiment 2. Proportion yes responses to test objects that matched deformable and rigid exemplars in shape, color or material for children at each age level. * denotes performance different from chance at $p < .05$ level.

because judgments of the similarity of shape and material test objects are made independently. This suggests that we may see very different patterns of behavior in these two tasks even when children access the same underlying knowledge.

Model

To probe these task differences in greater detail, we simulated performance in the forced choice and yes/no versions of the novel noun generalization task by adapting two recent dynamic field models. The goal of these simulations is to test the claim that very different patterns of behavior can arise in these tasks even when the same stimuli are used and the same knowledge structures are accessed. If this is the case, it suggests that some of the differences observed in the previous experiments may arise from the specifics of the real-time processes that turn perceptual inputs into responses in novel noun generalization tasks.

Insights into these processes come from work by Spencer and colleagues modeling the dynamics of responses in discrimination (same/different) and forced choice tasks (Simmering, Spencer, & Schöner, in press; Spencer, Simmering, & Schutte, in press). Our model, pictured in Figure 3, is an extension of the Dynamic Neural Field Theory (DNFT), a general theory of spatial working memory. The x-axis in each panel of Figure 3 shows a set of neurons arranged by "similarity". Neurons that are tuned to respond, for instance, to similar perceptual features would be close neighbors along this dimension, while neurons that are tuned to respond to dissimilar features would be far from one another along this dimension. The activation of each neuron is plotted along the y-axis. Time is shown along the z-axis as the sequence of events in a trial unfold.

Importantly, neurons in this model interact according to a local excitation/lateral inhibition function. This means that neurons with similar "preferred" inputs will excite one another while neurons tuned to very different inputs will inhibit each other. This allows the network to form stable peaks of activation that represent behavioral decisions to, for instance, select a particular input in a forced choice task. It is also possible, however, that the model will fail to form an activation peak. Whether this occurs depends on the similarity of inputs and the resting level of the neurons in the field. The critical differences between the forced choice and yes/no versions of the novel noun generalization task can be captured in this general framework. Such differences emerge from differences in the strength and time structure of the inputs, and in the dynamics of the response field.

Forced Choice Model In the forced choice version of the novel noun generalization task, the child is presented with two test objects at the same time and encouraged to pick one on each trial. Thus, the forced choice version of the model (top panel of Figure 3)is also presented with two test stimuli at the same time and encouraged to pick one—that is, to form a peak of activation centered at one input or the other. Note that the exemplar (the leftmost peak in the input field) is also present throughout the trial, but its activation is lower because it is farther from the child.

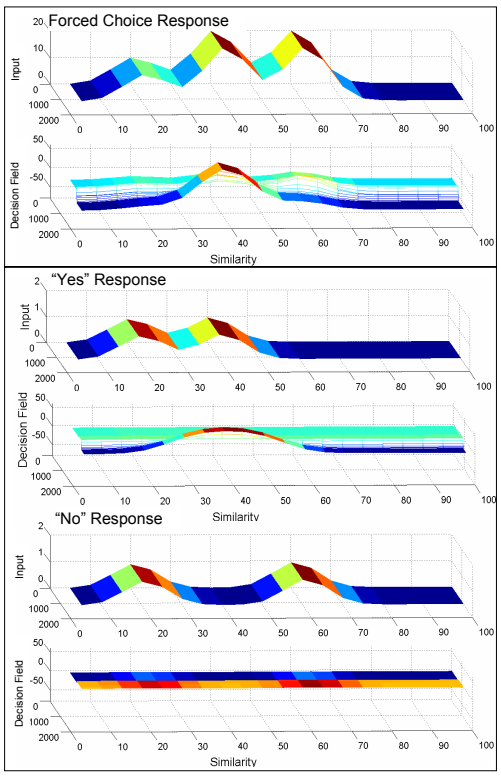

Figure 3. The models of the forced choice (top panel) and yes/no (bottom panel) tasks.

Conceptually, the forced choice version of the novel noun generalization task presents a more constrained type of decision. To capture this, the resting level of the neurons is set to a relatively low level at the beginning of the trial, and the inputs are strong. Thus, the field reflects the input strongly and is competitive, allowing for a detailed "comparison" between stimuli. It is this competition between inputs that is the basis for picking one test object over the other. As can be seen in the decision field of this model, at the start of the trial (back of figure) all three inputs are fed into the field. The resting level of the neurons in this field is raised at time X, corresponding to the boost of activation the child receives when the tray with the test objects is slid forward. In the model, this change increases competition among the neurons and forces the creation of a single stable peak centered over one of the test objects. The model's choice corresponds to the location of this peak along the x-axis.

Yes/No Model In the yes/no version of the novel noun generalization task, the child is presented with each test object individually and must make a yes or no response for each. Thus, the yes/no model is also presented with each input separately. The middle two fields of Figure 3 present a simulation where there is relatively high similarity between the exemplar and the test object, while the bottom panel shows a simulation with relatively low similarity. As above, the exemplar (leftmost peak in the input fields) is present throughout the trial but at a lower activation strength.

Conceptually, the yes/no version of the task presents a less constrained type of decision. Consequently, as long as

inputs are reasonably similar a "yes" decision can result. To capture this, the resting level of the neurons in the field is set at a high level and the individual inputs are weak. Thus, the field is more interactive, allowing more blending of the stimuli and good sensitivity to overlap in the input. It is this overlap that is the basis for yes/no decisions in this task. As can be seen in Figure 3, when the inputs are close together (corresponding to a test object that is similar to the exemplar) the locally excitatory interactions among neurons will cause the activation associated with these stimuli to blend and increase over time, ultimately combining to form a single peak. If this peak reaches a critical threshold—an activation level above 0—the model responds "yes". As can also be seen in the figure, however, when the input peaks are farther apart (corresponding to a test object that is less similar to the exemplar), the peaks do not blend in the response field. Thus, no above-threshold peak is formed and the model responds "no".

Simulations At issue is whether the differences between the forced choice and yes/no versions of the novel noun generalization task might mean that a young child's performance in the two tasks will differ even when the same stimuli are used. To examine this, we gave the same inputs to each version of the model and recorded the responses. The input consisted of Gaussians representing the relative similarity of the exemplar and the shape- and material-matching test objects. Note that the exact same Gaussians were input to both models. The similarities of the inputs captured the proposal that for deformable things children view things that are the made of the same material as more similar than things that are the same shape. It is important to note, however, that while these proposals have support in the literature (Subrahmanyam, Landau, & Gelman, 1999) the veracity of these relative similarities is not the critical issue here. Rather, the question is whether giving these same inputs to two models that capture different tasks produces different performance.

This answer is "yes". When these inputs were given to the forced choice model, the peak that formed was centered at the input location of the material-matching test object. In contrast, when these inputs were given to the yes/no model, the model generated a yes response for both test objects. In other words, the model generalized the novel name for the deformable exemplar according to similarity in material in the forced choice task, but generated a relatively non-specific response in the yes/no task.

Discussion

The simulations confirm the prior analysis of the task—the very same inputs to the models created vastly different behavior in these two tasks. This further suggests that children who have the same underlying knowledge structures, should perform differently when tested with the same stimuli in the two different versions of the task. To test this, in Experiment 3, we ran children at the same vocabulary level in the forced choice yes/no versions of the task with the same stimuli.

Experiment 3

Methods

Participants Thirty monolingual, English-speaking children, 18 girls, 26 boys, (M = 31m 19d, range = 30m 0d – 32m 24d), were recruited from the same database as the previous studies. None of the children had participated in the previous studies. Roughly half of the children participated in a Forced Choice task (6 females, 8 males) and half in a Yes/No task (6 females, 10 males). Children in the forced choice and yes/no conditions did not differ in age (Ms 31m 32d and 31m 16d, respectively) or total vocabulary (Ms 621 and 644, respectively), $t(28) = .822$, *ns* for age and $t(26) = .99$, *ns* for total vocabulary.

Stimuli, Design, and Task The same stimuli and tasks used in Experiments 1 and 2 were used in the forced choice and yes/no conditions (respectively) of this experiment.

Results

The top panel of Figure 4 shows the proportion of shape *choices* for rigid and deformable exemplars. As can be seen in this figure, when asked to choose whether a novel name for a *rigid* exemplar should be generalized to a shape- or material-matching test object, 31-month-old children picked the shape-matching test object. In contrast, when asked to choose whether a novel name for a *deformable* exemplar should be generalized to a shape- or material-matching test object, 31-month-old children picked the material-matching test object.

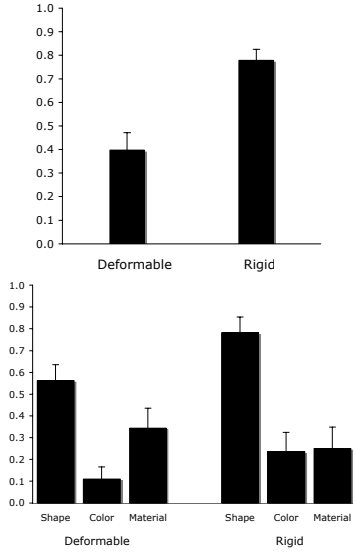

Figure 4. Data from Experiment 3.

Data from the Yes/No condition are pictured in the bottom panel of Figure 4**.** Overall the 31-month-old children in this experiment said yes to test objects that matched the exemplar in shape more often than those that matched the exemplar in color or material. This tendency was modulated by the rigidity of the exemplar such that children said yes to shape-matching test objects more when the exemplar was rigid than when it was deformable. Nevertheless, it is also clear in the figure that children were more likely to say yes to test objects that matched deformable exemplars in shape than those that matched these exemplars in material.

In a final analysis we compared the yes/no and forced choice data directly by converting the yes/no data to proportion of shape choices via the Luce choice rule (Luce, 1963). Specifically, the proportion of shape choices for a given stimulus set was taken to be equal to the proportion of

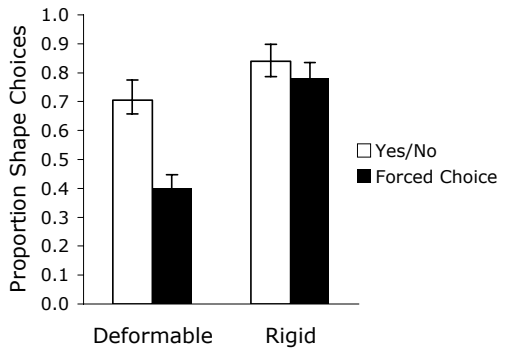

Figure 5. Direct comparison of data from the two conditions of Experiment 3.

yeses to shape-matching test objects divided by the sum of the proportion of yes responses to shape- and material-matching test objects. The proportion of shape choices made when a rigid exemplar was named did not differ across task. Importantly, however, the proportion of shape choices made when a deformable exemplar was named differed markedly across tasks. In particular, children generalized novel names for deformable exemplars by shape in the yes/no task but by material in the forced choice task.

Discussion

These results, then confirm the task analysis and the results of the model; whether 31-month-old children generalize names for deformable stimuli by shape depends on the task.

General Discussion

Taken together, the data from Experiment 3 and the model suggest that the specific processes that bring children's knowledge to bear in a moment in time are critical to understanding the developmental décalage in young children's naming of deformable stimuli. Further, this case study and model suggest the importance of viewing knowledge as created in the moment out of the interaction between the child's prior history of perceiving and acting and the specifics of the context. The bigger lesson from this case study, then, is that knowledge is not all or none, but incremental. It must be combined with the here-and-now of the specific task and realized in real-time activations. This means that understanding of the processes that support young children's early noun learning, for example, will come from detailed analysis of the knowledge children bring to the task, the moment-by-moment unfolding of the task, and the interaction of these factors. The model presented here is intended as a first step in this direction. The next step in this program of work will be to capture the full pattern of developmental data across the entire age range and in both forced choice and yes/no tasks.

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