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The Influence of Co-occurrence Probability on Knowledge Generalization in Preschool-Age Children

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Abstract

Prior research had documented that semantically-similar labels that co-occur in child-directed speech promote generalization in young children. The present study examined whether co-occurrence probability – in the absence of semantic similarity – can influence children’s inferences. Four- and five-year-old children were exposed to an auditory speech stream consisting of trisyllabic nonsense words (e.g. “golabu”) that were concatenated into a continuous speech stream. After listening to the stream, children were given a label extension task where the first two syllables of a nonsense word were assigned to a novel target object (e.g. “gola”); children were asked to choose which of the three test items should be referred to by the remaining syllable of this nonsense word (e.g., “bu”; Experimental condition) or by a syllable from a different nonsense word (e.g., “ti”; Control condition). Children’s generalization performance in this task was similar to results of previous research that used natural rather than artificial language stimuli. These results are consistent with the notion that low-level, automatic processes can influence performance on high-level reasoning tasks.

Keywords: Labels. Statistical Learning. Generalization. Cognitive Development. Categories.

Introduction

A longstanding issue in cognitive development research centers on how children acquire knowledge. At the core of this issue is whether children’s learning is “theory-based” – guided by top-down, domain-specific mechanisms – or whether more automatic, domain-general mechanisms are sufficient to account for the vast amount of information that children acquire in the early years of life. These contrasting views are fueled in part by findings that, on the one hand, young children are capable of exhibiting adult-like performance in a variety of higher-order reasoning tasks (Gelman & Coley, 1990; Gopnik & Sobel, 2000; Goswami & Brown, 1990; Keil, Smith, Simons, & Levin, 1998) while, on the other hand, children’s performance on such tasks is often driven by low-level perceptual, memory, and attentional factors (Fisher & Sloutsky, 2005; Rattermann &

Gentner, 1998; Sloutsky, Kloos, & Fisher, 2007; Rakison, Lupyan, & Oakes, 2008; Smith, Jones, & Landau, 1996).

A local instantiation of this issue concerns the mechanisms underlying children’s generalization of new knowledge. Many studies investigating this phenomenon have concluded that, similar to adults, young children’s generalization is based on conceptual knowledge (Booth, Waxman, & Huang, 2005; Gelman & Coley, 1990; Gelman, & Medin, 1993; Jaswal, 2004; Jaswal & Markman, 2007; Welder & Graham, 2001). For example, in their seminal study Gelman and Markman (1986) provided children the opportunity to generalize a property from a target object (e.g. a “rabbit”) to either a test item that shared appearance but not category similarity with the target (e.g. a similar looking “squirrel”), or a test item that shared category but not appearance similarity with the target (e.g. a dissimilar looking “rabbit”). In this study, category similarity was conveyed by each objects’ label: labels could be either identical (e.g. rabbit–rabbit) (Experiment 1) or synonymous (e.g. bunny–rabbit) (Experiment 2). Gelman and Markman found that children extended properties to categorically similar items at above chance levels for both identical and synonymous labels (at 67% and 63%, respectively).

These findings are consistent with a knowledge-based account of children’s generalization. However, it has been suggested that children’s induction with identical labels may be *label-based* rather than *category-based* (Sloutsky & Lo, 1999; Sloutsky & Fisher, 2004). In particular, if labels are perceived by children as object features then identical labels should increase the overall perceived similarity of compared entities. A mathematical model which construes labels as object features was able to account for Gelman & Markman’s findings (1986; Experiment 1) as well as several novel findings (Sloutsky & Fisher, 2004).

At the same time, the finding that not only identical but also synonymous labels promote generalization in preschool-age children has presented a challenge to the similarity-based account children’s generalization: as synonymous labels are not identical or even phonologically similar, they should not increase the overall perceived

similarity across presented items. Arguably, the only reason children should generalize from a “bunny” to a “rabbit” is because these labels refer to items of the same kind.

However, it has been recently suggested that some synonymous labels used in prior research not only referred to objects of the same kind but also were likely to co-occur in child-directed speech (Fisher, 2010). Specifically, according to the CHILDES database (MacWhinney, 2000) the following synonym-pairs used in Gelman and Markman’s (1986) study co-occurred in natural speech of children or their caregivers: bunny- rabbit, puppy- dog, and kitty-cat; other synonym-pairs were unlikely to co-occur (e.g., rock-stone, cobra-snake, dessert-sand). Co-occurrence has been shown to give rise to strong lexical associations (Brown & Berko, 1960; McKoon & Ratcliff, 1992); therefore, it is possible that children’s generalization with co-occurring synonyms was the result of lexical priming rather than category-based reasoning. Under this interpretation, when children extend a property of a “bunny” to a “rabbit”, it is not because they reason that bunnies and rabbits are the same kind of animal, but instead because the label “bunny” primes the label “rabbit” during the course of the task. Thus, it is conceivable that overall above-chance generalization with synonymous labels in prior research stemmed from averaging across two different types of items (i.e., co-occurring synonyms and non-co-occurring synonyms).

To explore this possibility, Fisher, Matlen, & Godwin (in press) presented a group of four-year-old children and adults with a property induction task with both co-occurring semantically-similar labels (e.g., bunny-rabbit) and non-co-occurring semantically-similar labels (e.g. alligator-crocodile) (the type of labels was manipulated within-participants). Importantly, following the property induction task children’s knowledge of all labels used in the study was tested in a task similar to the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997); findings from this task suggested that 4-year-old children were nearly at ceiling in identifying pictures using co-occurring and non-co-occurring labels (99% of correct responses in both conditions).

Fisher et al (in press) findings indicated that adults overwhelmingly gave category-based responses, regardless of the co-occurrence probability of labels. In contrast, 4-year-old children were more likely to provide category-based responses in the co-occurring condition than in the non-co-occurring condition (74% and 51%, respectively). Moreover, the rate of category-based generalizations in 4-year-old children did not exceed chance level (50%) in the non-co-occurring condition. At the same time, when children’s responses were aggregated across the co-occurrence conditions, the overall rate of category-based responding was above chance (63% - identical to that reported by Gelman & Markman, 1986). A follow-up study indicated that the majority of children do not reliably give category-based responses with non-co-occurring

semantically-similar labels before six years of age (Fisher et al, in press; Experiment 2).

In a related study, Fisher (2010) found a similar pattern of performance in a label generalization task. In particular, in that study children and adults were presented with several novel objects and told the name for one of these objects. Participants were then asked which of the other objects would be more likely to be referred to by a semantically-similar label. For example, participants could be told that the target objects “is called a bunny in a far away place” and then asked which of the three test objects might be “called a rabbit in the far away place”. Regardless of the co-occurrence probability of labels, adults overwhelmingly chose high-similarity test items, reasoning that semantically-similar labels should refer to perceptually similar objects. However, 4-year-old children exhibited this pattern of responding only with co-occurring labels, whereas their choices of high similarity items did not exceed chance with non-co-occurring labels.

Overall, extant research provides evidence in support of the possibility that synonym-based reasoning has a more protracted developmental trajectory than previously believed. Furthermore, it appears that children’s successful generalization with some synonymous labels is due to co-occurrence probability rather than semantic similarity.

However, all previous studies examining this issue used natural language stimuli; therefore, it is possible that children’s performance was influenced by factors other than co-occurrence probability, such as familiarity and frequency of occurrence. Fisher et al (in press) evaluated these possibilities and found no support them. At the same time, given the nature of the stimuli it is difficult to completely rule out confounding factors. It is also possible that co-occurrence information is necessary but not sufficient to influence children’s generalization: in other words, co-occurrence may facilitate children’s ability to perform synonym-based generalization, yet co-occurrence in the absence of semantic similarity may not promote generalization. The present study was designed to test whether co-occurrence could influence generalization in the absence of semantic similarity information, while also eliminating potentially confounding factors associated with using natural language stimuli in prior research.

Towards these goals, we utilized an experimental approach often employed in the statistical learning literature (Aslin, Saffran & Newport, 1998; Saffran, Aslin, & Newport, 1996; Saffran, Newport, Aslin, Tunick, & Barrueco, 1998). In these studies, participants are typically exposed to an auditory speech stream consisting of a string of repeating syllables that comprise words of an artificial language. Within this stream, some of the syllables have low transitional probabilities, whereas other syllables had high transitional probabilities. Transitional probability is one way of capturing the co-occurrence relation of units in a language (Aslin, Saffran, & Newport, 1998). In most statistical learning studies transitional probability between syllables X and Y is calculated as:

Probability of $Y|X = (\text{frequency of } XY) / (\text{frequency of } X)$.

The speech stream is often designed such that the only cues to the word boundaries are the transitional probabilities of each syllable, and participants' task is to discriminate between "words" and "part-words" of this artificial language following exposure to it.

Using this paradigm, prior research has indicated that adults, young children, and preverbal infants are capable of segmenting words using the statistical structure of artificial languages (Aslin, et al., 1998; Saffran, et al., 1996; Saffran et al., 1998). Moreover, it has been shown that infants are capable of using the statistical information to learn novel object-label pairings (Graf-Estes, Evans, Alibali, & Saffran, 2007) and that adults find it more difficult to learn object-label pairings when words are inconsistent with the statistical structure of an artificial lexicon (Mirman, Magnuson, Graf Estes, & Dixon, 2008).

In the present study we adapted the statistical learning paradigm as follows. We exposed preschool-age children to a speech stream that consisted of four artificial trisyllabic words used in the Saffran et al (1996) study (e.g. golabu, padoti, etc). Each syllable had a 100% transitional probability within words and a 33% transitional probability between words. After listening to the stream, children were presented with a label generalization task analogous to that in Fisher (2010). Specifically, children were presented with a set of novel objects consisting of a Target and three Test items varying in the degree of similarity to the Target. The Target object was labeled using a part-word from the artificial language (e.g. "gola"), and children were asked to generalize a Test label that was either consistent with the co-occurrence information of the artificial language (e.g. "bu") (Experimental condition) or inconsistent with it (e.g. "ti") (Control condition).

Prior research indicated that four-year-olds in this label extension task generalized synonymous labels to high similarity test items when labels co-occurred in child-directed speech but generalized labels at chance level to test items when labels did not co-occur (Fisher, 2010). In the present study – where there was no semantic information present – we predicted that, if children's performance in prior research was influenced by co-occurrence probability rather than semantic similarity of labels, then children would extend Test labels to highly similar items *only* when the labels were consistent with the statistical structure of the artificial language (i.e. analogous to children's performance with co-occurring synonyms in Fisher, 2010). In contrast, we expected that children might not show this pattern of responding (i.e., choosing highly similar test items) when Test labels were inconsistent with the statistical structure of the artificial language. However, if children's generalization in prior research was not driven by the co-occurrence of synonyms in natural language, in the present study children should exhibit similar pattern of responses whether Test labels are consistent or inconsistent with the

statistical structure of the artificial language. These predictions were tested in the experiment reported below.

Method

Participants

Participants were 41 four- and five-year-old children ($M = 5.08$ years, $SD = .67$ years, 16 girls, 23 boys) recruited from a university lab school. Two children were excluded because they were learning English as a second language. All other children were native English speakers.

Materials

Language materials consisted of four, trisyllabic nonsense words used in prior research (e.g., Saffran, Aslin, & Newport, 1996): "golabu", "padoti", "bidaku", and "tupiro". A female native English speaker was recorded pronouncing each word individually and each recording was then edited to be approximately 800ms in duration. The recordings were used to create a speech stream in which each word occurred a total of 105 times. Because the present study did not test whether children are capable of segmenting words using transitional probabilities alone (there is ample prior research showing that they are capable of it), we included a short 200ms pause in between each word in order to facilitate segmentation. All syllables had a 33% between-word transitional probability and a 100% within-word transitional probability. In total, the speech stream lasted seven minutes in duration.

Visual stimuli consisted of four sets of four novel objects (see Figure 1 for an example). These stimuli were a subset of picture sets used in Fisher (2010). Each set was comprised of a target object and three test objects, where one of the test objects was highly visually similar to the Target item (High similarity item), one test object was moderately similar to the Target item (Moderate similarity item), and one test object was dissimilar from the Target item (Low similarity item). The level of similarity of each test items to the target was confirmed in a separate calibration study reported in Fisher (2010). The location of each test item relative to the target (i.e., directly below, below and to the right, or below and to the left) was randomized for each participant. Visual stimuli were presented on a laptop computer and their presentation was controlled by SuperLab-3 software.

Procedure

Children were tested individually in a quiet room at their school by hypothesis-blind experimenters. The experiment consisted of two parts: the listening phase and the generalization phase. The experimenter first told the children that they would be coloring pictures and that afterwards, they would get to play a game.

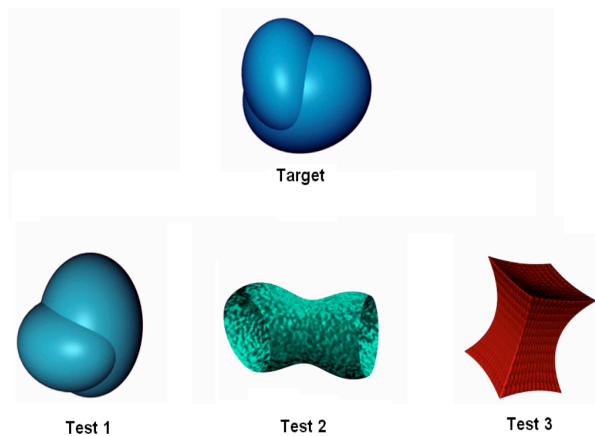


Figure 1. A sample set of visual stimuli used in the present Experiment. Test 1 is a High Similarity item, Test 2 is a Moderate Similarity item, and Test 3 is a Low Similarity item.

Once children were coloring, the experimenter played the speech stream from a laptop computer. The listening phase lasted for approximately 7 minutes¹.

After the listening phase, the experimenter told children that they were going to play a game where they would have to guess the names of objects on a different planet (i.e. the generalization phase). The experimenter showed the first picture set, which was comprised of a target item and three test items. The experimenter then labeled the target picture with a bisyllabic part-word from the artificial language. In the Experimental condition, the experimenter asked the child which of the test items should be referred to by a monosyllabic label that completed the part-word according to the artificial language. For example, the experimenter would say, “On a different planet, this one is called a gola” while pointing to the target picture. The experimenter would then say, “if this one’s a gola, which one’s a bu?”. Children responded by pointing to one of the three test items. In the Control condition, the procedure was identical except that the test label was a syllable that was inconsistent with the statistical structure of the artificial language (e.g. if the target label was “gola”, the test label was “ti”).

Children completed eight trials, two for each of the four artificial words. A full list of linguistic stimuli is provided in Table 1. Trials were presented in one of two orders (either trials 1 – 8 in Table 1, or the reverse).

¹ Due to technical difficulties, some of the pauses between words were longer at some points in the speech stream, which thereby extended the listening phase by about a minute. This technical problem affected 10 out of 39 participants. However, children who experienced this difficulty did not perform differently from the rest of the children, independent samples $t(37) = .12$, *ns*, and were therefore included in all analyses reported.

Table 1: List of Target and Test labels.

Trial	Target Label	Test Label: Experimental Condition	Test Label: Control Condition
1	Gola	Bu	Ti
2	Pado	Ti	Bu
3	Bida	Ku	Ro
4	Tupi	Ro	Ku
5	Pado	Ti	Bu
6	Gola	Bu	Ti
7	Tupi	Ro	Ku
8	Bida	Ku	Ro

Results

Proportion of choices of each Test item was calculated for each participant and averaged across participants. The rate of choosing High Similarity, Moderate Similarity, and Low Similarity test items in the Experimental condition was 56%, 23%, and 20%, respectively. In the Control condition, the rate of choices of High Similarity, Moderate Similarity, and Low Similarity test items was 36%, 33%, 32%, respectively. Children’s performance on High Similarity items in the present study is displayed in Figure 2. Children in the Experimental condition chose the High Similarity items at above chance level (chance in this experiment was 33%) one-sample $t(19) = 2.78$, $p < .05$, whereas children in the Control condition chose the High Similarity items at a level no greater than chance, one-sample $t(18) = .29$, $p = .76$. An independent samples t-test showed that children in the Experimental condition were marginally more likely to choose High Similarity items when compared to children in the Control condition, $t(37) = 1.85$, $p = .07$.

To investigate performance at an individual level, we classified participants into similarity-based and non-similarity-based responders. A similarity-based responder was defined as a participant who chose High Similarity test items on at least 6 out of 8 trials (75%; binomial $p < .02$). In the Experimental condition, 8 of 20 participants qualified as similarity-based responders, while only 3 of 19 participants qualified as similarity-based responders in the Control condition. The association between responder type and experimental condition was marginally significant, $\chi^2(1, 39) = 2.82$, $p = .09$.

It is worth noting that the results obtained in this study with artificial language stimuli are similar to those reported by Fisher (2010) with natural language stimuli. For instance, in Fisher’s study the rate of choosing High Similarity test items among 4-year-old children was 65% for co-occurring synonyms and only 39% for non-co-occurring synonyms.

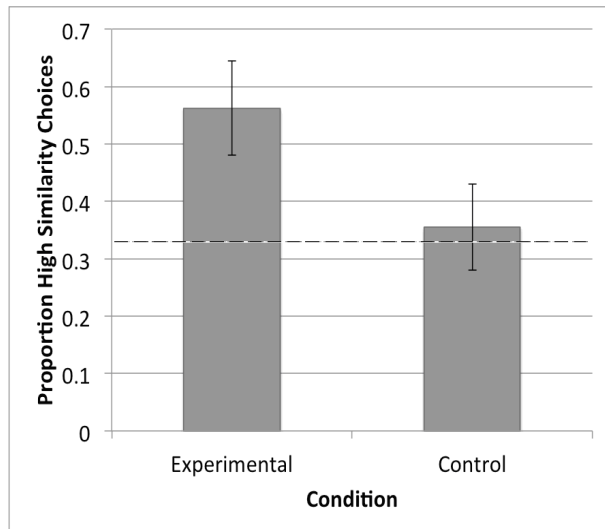


Figure 2. Proportion of High Similarity choices by condition. The dashed line indicates chance performance.

Discussion

The aim of the present experiment was to explore whether it is possible for label co-occurrence information to influence performance on a generalization task in the absence of semantic similarity. The results of this experiment provide preliminary support for this possibility. Specifically, children extended novel part-words to highly similar items at levels greater than chance when the part-words were consistent with the statistical structure of the artificial language, but not when the part-words were inconsistent with the statistical structure of the artificial language. These findings suggest that – at least in principal – the results of earlier research concerning children’s generalization could indeed have been driven largely by co-occurrence information.

It is important to acknowledge that the present work is limited in that it is primarily preliminary in nature. Specifically, we did not contrast children’s performance on a label generalization task after listening to the speech stream with a condition in which no speech stream is presented, and this contrast remains to be the focus of our future work. Nevertheless, to our knowledge, the present findings are novel in that they provide support for the idea that co-occurrence information alone may be sufficient to influence children’s performance on generalization tasks.

In addition to informing the study of children’s generalization, we believe that this line of research can also help to inform our understanding of some fundamental issues in cognitive development. In particular, there is presently an active debate focusing on whether children’s performance in high-level cognitive tasks can be explained by association-based, domain-general processes or whether top-down domain-specific mechanisms need to be postulated (e.g., Gelman, 2003; Keil, 2005; Sloutsky, 2010; Smith, Colunga, Yoshida, 2010; Waxman & Gelman, 2009).

While the present study does not rule out the possibility that children use semantic knowledge to perform generalization tasks, it suggests that it is possible for children to perform such tasks relying on associative knowledge alone. This finding is consistent with the notion that domain-general mechanisms help children acquire knowledge (Christie & Gentner, 2010; Saffran, Pollak, Seibel, & Shkolnik, 2007) and that low-level associative learning can give rise to intelligent behavior in development (Sloutsky & Fisher, 2008; Smith, Jones, & Landau, 1996).

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