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Learning Novel Neighbors:
Distributed mappings help children and connectionist models.

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Abstract

The current study examines whether a word that is phonologically similar to more words the child already knows is easier to acquire than a word that is unlike other words. Children aged 20 and 24 months were taught two new words: "wat," which is similar to many words children already know, and "fowk," which is not. Learning of the novel words corresponded to neighborhood density in the individual child's vocabulary. We also examined the influence of prior semantic knowledge on the acquisition of novel words in a connectionist network. Together with the empirical data, this model provides novel insights into how similarity at the phonemic level influences acquisition of semantics.

Keywords: word-learning; lexical neighborhoods; connectionist modeling

Introduction

A great deal of research has investigated factors that might influence toddler's rapid word learning. The current study explores how children's developing knowledge of word forms might influence their acquisition of new words. In particular, we examine whether a word that is similar to several words the child already knows (that is, a word that has a dense lexical neighborhood), is easier to acquire than a word that is similar to fewer already-known words. Below, we discuss prior research suggesting that vocabulary knowledge influences word learning, review what is known about lexical neighborhoods, and suggest how neighborhood properties could influence lexical acquisition.

The effect of prior knowledge on word learning

The extensive body of research on early word learning suggests that young children take advantage of many sources of information when acquiring a new word, including the structure of the vocabulary they've learned previously. For example, children who have been exposed to a training vocabulary dominated by names for solid things in categories organized by shape develop a precocious bias to attend to shape in word learning tasks, and demonstrate accelerations in later vocabulary development (Samuelson, 2002). Thus, similarity between known entries at the semantic level (count nouns that name solid things in categories organized by shape) can help children learn more words. Similarly, Tomasello, Mannle and Werdenschlag (1988) reported that children were better able to learn a new word when they already knew the name for a conceptually-similar referent. They argued that children find it easier to learn a word when they already have a contrastive referent in memory. Both of these prior studies suggest that prior semantic knowledge can influence the ease with which children learn new words. The current study examines whether early word learning is also aided by similarity between known entries at the phonemic level.

The role of neighborhoods on word learning

According to the Neighborhood Activation Model (Luce & Pisoni, 1998), words in the phonological lexicon are organized according to their phonological similarity to other words. For example, the word "cat" is located in a dense neighborhood, as it is similar to many other English words (*bat*, *cot*, and *cap*, among others), whereas "vogue" is located in a sparse neighborhood (being similar to only four words: *rogue, vague, vote*, and *vole*). These storage differences can affect how easily those words are accessed (Luce & Pisoni, 1998). It is possible that such differences might also influence learning of new words.

There are multiple ways lexical neighborhoods could influence word-learning. Neighbors could influence the creation of a semantic representation, the creation of a word-form representation, or the linkages between the two (see Storkel, 2004). Neighbors could have effects on perception (children might mishear an unknown word as being its well-known neighbor), attention (a word with more neighbors may sound more "English-like", attracting attention; see Jusczyk, Luce & Charles-Luce, 1994), memory (a word with more neighbors might be easier to remember upon first hearing; e.g., Roodenrys et al., 2002), or might be easier to access for production e.g., Newman & German, 2002, 2005). Phonological neighbors could also provide contrastive representations, as noted by Tomasello et al. (1988). Thus, neighborhood density could theoretically influence acquisition of a novel name at several different stages of processing—from perception of the novel form to formation of a conceptual representation of the word's meaning.

Three studies have examined the effect of phonotactic probability on lexical acquisition. Phonotactic probability

refers to the frequency with which the phonemes and phoneme sequences in a word occur in the language, and is a related concept to that of neighborhoods, in that items that have many neighbors tend to contain high-frequency phonemes. Storkel and Rogers (2000; Storkel, 2001) found that children across a range of ages were better able to learn words that were composed of common vs. rare sound sequences. Moreover, Storkel found evidence suggesting that phonotactic probability played a role both in the formation of a semantic representation and in associating that semantic representation with a word form.

In contrast, Heisler (2005) examined 4-year-old children's and adults' learning of bisyllabic nonce words, in which the probability of the medial consonant cluster, and the neighborhood density of the component syllables (but not the entire word), were varied. She found that phonotactic probability influenced motor production stability (a kinematic measure of motor skill), whereas neighborhoods influenced the accuracy of either production or the phonological representation.

Retrospective research (Storkel, 2004) suggests that children's early-acquired words (particularly words low in frequency) reside in dense neighborhoods, supporting the idea that existing representations can influence future lexical acquisition. Similarly, Coady and Aslin (2003) found that children's first words came from what were dense neighborhoods in adult lexicons (see also Charles-Luce & Luce, 1990; 1995; Dollaghan, 1994 for debate on this point), and that children's average neighborhood density was larger than that for adults, suggesting a learning advantage for words from dense neighborhoods.

Taken together, the literature confirms the influence of phonotactic probability on word learning and suggests a corresponding influence of neighborhood density. Importantly, however, most of these studies have examined effects in older children; only two studies have examined neighborhood effects in toddlers in the early stages of vocabulary acquisition. Hollich, Jusczyk & Luce (2002) familiarized 17-month-olds with a list of words, and then taught them the name of a novel object. Children were better able to learn the novel object when it was dissimilar to the familiarized words. However, none of the familiarized (neighborhood) words were chosen based on whether the children already knew them. Thus, these items were not true neighbors, and the difference in performance could have been the result of a momentary alteration in children's attention to the sound structures. It is thus unclear whether these results would generalize to situations in which the "neighbors" are words already known to the child (but not necessarily heard recently).

More recently, Swingley and Aslin (2007) presented 19-month-olds with a novel object, and labeled it with a sequence that was either similar to a word they were likely to already know (such as *tog*, similar to *dog*) or one that was not similar to any familiar words (such as *meb*).

Children learned the new nonneighbors better than the new words that were neighbors to existing words. Thus, the existence of a known word impaired children's learning of a new neighbor in this study.

Swingley & Aslin's study focused on words with a single, well-known neighbor (an "entrenched lexical competitor," in their terms). However, much of the research on lexical neighborhoods with adults has suggested that neighborhoods show a "ganging" effect: that is, the effect of neighbors is driven by having a *number* of similar, well-known words, rather than a single well-known word. If this is the case, children's learning of new words with many neighbors might show a different pattern than their learning of words with a single, well-known neighbor.

The current study

The goal of the present study was to examine the role of neighborhood density (rather than mere existence of a neighbor) on word learning and whether such effects vary with the child's existing vocabulary level. We presented children with a word-learning task involving two words, one with many pre-existing neighbors in the children's lexicons, and one with few neighbors. We recruited children from two different age levels, 20 and 24 months, to examine neighborhood effects at different stages of word learning and to compare effects based on age to those based on vocabulary. We also examined the influence of prior knowledge on the acquisition of novel words in a connectionist network. Together with the empirical data, this model provides novel insights into the how similarity at the phonemic and semantic levels interact to influence new word acquisition.

Experimental Method

Participants

Twenty-four 24-month-old children (23m 20d – 25m 21d), and 24 20-month-old children (19m 21d – 22m 7d) participated, with equal numbers of boys and girls at each age. Seven additional 24-month-olds and 11 additional 20-month-olds were tested but excluded from analysis for fussiness (n=4), not completing the task (n=6), experimenter error (n=7), or equipment failure (n=1).

Materials

Words. The nonwords "fowk" and "wat" were used. Fowk has only 3 lexical neighbors in adult lexicons (fake, fowl, and a swear word), along with two similar words that are not technically neighbors by a one-phoneme substitution rule (fork and folk). Of these, only fork is common in children's lexicons according to the LEX database (Dale & Fenson, 1996). The word fake does appear once as input to a child in the Bernstein Ratner corpus (Bernstein Ratner, 1984; MacWhinney, 2000). It therefore might be heard by some children, but this is unlikely to be consistent. Thus, while the word fowk is a

potential word in English, it is likely to have only few (if any) neighbors in the lexicons of young children.

Wat has 20 neighbors in adult lexicons (at, that, bat, cat, chat, fat, gnat, hat, mat, pat, rat, sat, wag, wet, wait, wit, whack, what, wheat, white), many of which are common in speech to and by young children. According to the LEX database, the words *hat, cat, what, wet* and *that* are likely to be in most children's receptive lexicons by the ages tested here, and parents in the Bernstein Ratner corpus used 11 "wat" neighbors, suggesting that many children in the range tested will have heard at least some of the neighbors to wat.

To confirm our word selections, parents completed a vocabulary checklist based on the MacArthur-Bates Communicative Development Inventory (Fenson et al., 1994) with additional neighbors to the target words added in a separate section. Participants at both ages had significantly more neighbors for wat than for fowk; the size of this difference was larger in the production data at the older age.

Object stimuli. Two sets of novel target stimuli were created. Each target set contained three category exemplars that were highly similar and a contrast item that differed in shape, color and material from the category examples. In addition, two sets of novel foils were created. Each foil set contained three similar items that were different from the category exemplars in shape, color and material. In addition to these items, a set of small toys familiar to 24-month-olds were used as warm-up items for the production tests.

Procedure

Training phase. The experimenter presented the child with two of the exemplars from the first target stimulus set; the child played with these for three minutes while the experimenter named the items 20 times in a naturalistic manner. The experimenter was not allowed to use the word "that" (a neighbor to "wat") at any point during the experiment[1]. Half-way through the 3-min. training period the experimenter produced the contrast item for that set and pointed out the contrast explicitly (e.g., "Look at this, this is not a wat/fowk.") before putting the contrast item away. After the three minutes for the first target set was completed this procedure was repeated for the other target set. The procedure was then repeated for each of the two foil sets with the exceptions that these items were not named and no contrast items were presented. Following this, the experimenter, child and parent colored as filler task during a five-minute delay period.

Testing. Children were first tested on comprehension, via both a looking and a handover measure, for both sets. The target set that was presented first during training was tested first. Children were then tested on production of the novel words. This entire testing sequence (comprehension and then production) was done first with the two exemplars that children had seen during training, and then again with the third exemplar that was not presented during training as a test of extension to a novel instance.

To test comprehension the experimenter placed one of the previously seen targets and one of the previously seen foils on the table, said "Look!" and counted to ten. The experimenter then instructed the child to look for the item five times (i.e., "See the wat/fowk, look at the wat/fowk, etc.) After this the experimenter placed the objects on a white tray, slid the tray towards the child and said "get the wat/fowk." If the child failed to respond, the prompt was repeated up to two times. The items were removed and the comprehension testing sequence was repeated for the other target set. Children's selections were not reinforced.

Production tests began with the naming of familiar items to encourage the children to talk. After the child produced names to three familiar items[2], the experimenter presented the first target exemplar, and asked the child to name it. The child was prompted up to four times. If the child correctly named a target they were praised heavily. If the child produced an incorrect word for a target (i.e. said "wat" to an exemplar previously labeled "fowk") the experimenter made a note and moved on to the next item without comment. The child was asked to name both previously seen exemplars for each target set.

After the production test with the familiar exemplars, the entire testing procedure (comprehension and production) was repeated with the generalization exemplars from each set (the ones the child did not see during training). In total, each child completed six looking and choice comprehension tests and six production tests (two trained and one novel exemplar in each of two sets).

Coding and data reduction

Comprehension in the looking and handover tests was coded from videotape by blind observers. For each task and age, 30% -35% of the data were recoded by a second observer; minimum agreement was .93.

Results

Results for 20-month-old children

Looking task. We first examined performance on the familiar-object trials, based on the proportion of time spent looking at the target vs. the foil. Overall, children looked at the named object longer than the foil for both items (61% for wat, 67% for fowk, both significantly above chance performance both t's(23)>2.77, p's<.05). There was no difference in performance on wat vs. fowk trials t(23)=1.34, *ns*. This was also the case in the novel trials, with scores of 58% for wat, 64% for fowk; only the

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[1] Data from an additional 9 24-month-olds and three 20-month-olds were not analyzed because the experimenter accidentally used the word "that".

[2] Data was excluded from 5 24-month-olds and 9 20-month-olds for failure to produce names for 3 familiar objects during the production phase.

looking time for fowk was above chance levels (wat: $t(23)=0.69$, ns, fowk: $t(23)=2.70$, $p<.05$).

Choice task. When children were asked to "get the wat", 20-month-olds chose correctly 73% of the time for previously-seen objects, above chance performance, $t(23)=3.41$, p<.001. For fowk, they chose correctly 65% of the time, which was not different from chance, $t(23)=1.77$, $p<.08$. For novel exemplar trials, averages were 71% and 54%, with only the former reaching significance, $t(23)=2.20$, p<.01; $t(23)=0.41$, ns. There was no difference on wat vs fowk trials for either stimulus set, $ts(23)>1.2$, ns.

Production task. Only 10 children made any correct productions during testing, although 8 children named one or both objects during training (7 named the fowk, 4 named the wat). On average, children produced the word wat 0.5 times (out of 3 opportunities), and produced fowk 0.63 times; these were not significant differences ($F<1$).

Results for 24-month-old children

Looking task. For familiar-exemplar trials, children looked at the named object longer than the foils for both words (68% for wat, 57% for fowk, with only the former being significantly above chance, $t(23)=5.78$, $p<.0001$ and $t(23)=1.38$, ns. There was a trend towards better performance on wat trials than on fowk trials, $t(23)=2.06$, $p=.05$, suggesting better learning for the high-density word. Children looked at both objects above change on the novel exemplar trials, $t(23)$ 2.31, p<.05 for the wat and $t(23)=3.30$, $p<.01$ for the fowk; these two did not differ, $t(23)=-0.55$, ns.

Choice task. For the familiar objects, children selected the target 91% of the time for wat (significantly above chance, $t(23)=10.74$, $p<.0001$), but only 60% of the time for fowk, $t(23)=1.16$, ns. This difference was significant, $t(23)=3.50$, $p<.05$. On novel exemplar trials, children chose the target over its foil at above chance levels for both wat $t(23)=3.44$, p<.01 and fowk, $t(23)=2.20$, $p<.05$, with no difference between the two, $t(23)=.64$, ns. In summary, children showed better learning for the dense-neighborhood item.

Production task. Only 9 children made any correct productions. On average, children produced wat 0.4 times (out of 3 opportunities), and fowk

0.63 times. These were not significant differences, $F(1,23)=2.67$, $p>.10$, although the trend was towards better production of fowk than wat.

Combined effects by age

The analyses of each age group separately suggest that 24-month-olds show a stronger neighborhood effect than do 20-month-olds. To further examine this possibility, we compared the two groups directly. An age x word ANOVA on the combined looking time data showed a significant interaction, $F(1,46)=5.73$, $p<.05$, with 24-month-olds showing better performance for wat (68% vs. 57%), and the younger children showing a bias towards fowk (67% vs. 61%). The choice data, however, reveal only an overall effect of word, $F(1,46)=7.70$, $p<.05$, with better performance on "wat" than "fowk" (79% vs. 63%). Although older children showed a trend towards slightly better performance, $F(1,46)=2.58$, $p=.11$, neither this overall age effect nor the interaction between age and word were significant ($F<1$).

Combined effects by neighborhood size

One possible reason for the ambiguity in results is that the effects are not based on age, *per se*, but rather based on vocabulary knowledge. Although 24-month-olds tended to have larger vocabularies than did 20-month-olds, this was not an absolute difference, and some younger children had larger vocabularies than some older children. Indeed, there was a positive correlation between the number of wat neighbors a child could say and their learning of that word, based on both looking time behavior to familiar wat exemplars ($r=.32$, $p<.05$), and on choice performance ($r=.30$, $p<.05$). Children who knew more neighbors for wat showed better learning of that word. There were no significant correlations for fowk, ($r=.04$ and $r=.05$ for looking time and choice). To examine these effects further, we split the children into two groups based on productive wat neighbors, excluding the middle nine children to ensure our groups were not overlapping. The few-neighbors group included five 24-month-old children and fourteen 20-month-old children; conversely, the many-neighbors group included thirteen 24-month-olds children and seven 20-month-old children. The looking-time data are pictured in Figure 1.
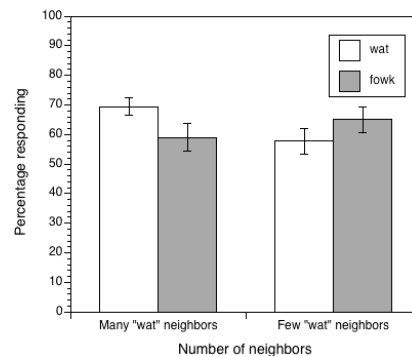

Figure 1: Looking time results by neighborhood group

Children with many wat neighbors looked longer at the wat than its foil, $t(19)=6.29$, $p<.0001$, but only marginally longer at the fowk than its foil, $t(19)=1.89$, $p=.07$, a significant difference $t(19)=2.14$, $p<.05$. They showed a similar pattern in their choice behavior (above-chance performance only for the wat, with a significant difference between the two trial types). Children with few wat neighbors, however, showed no significant difference between wat and fowk in either looking, $t(18)=1.43$, or choice $t(18)=1.30$. They looked longer at the fowk than its foil, $t(18)=3.49$, $p<.01$, but did not choose it more,

t(18)=0.83; they chose the wat at above-chance levels, *t*(18)=3.38, *p*<.001, but only looked at it marginally longer than the foil, *t*(18)=1.77, *p*=.09. Overall then, children with few neighbors showed only weak learning, while children with many wat neighbors evidenced learning of wat in both tasks, and better learning of wat than fowk

Discussion

These results suggest that the word forms in an individual child's lexicon influence that child's subsequent vocabulary acquisition. The fact that neighborhood size influenced learning of "wat" but not "fowk" suggests the effect was not one of general acquisition skill, but was more closely tied to the phonetic forms the child knew. Thus, children are better able to learn new words that have one or more similar phonological referents in their vocabulary.

Computational Connectionist Model

To examine this finding in more detail, a computational connectionist model was trained on a vocabulary of 250 1-syllable words, to correspond to a vocabulary similar in size to that of children at the ages tested in the experiment. The network's task was to translate an input pattern of activation representing the word's phonology into an output pattern of activation representing the word's semantics. The training corpus therefore consisted of input-target pairs such that input was a phonological representation of the word form, and the target was a semantic representation for the word. Semantic representations were randomly chosen vectors that were assigned arbitrarily to be paired with word forms. The network was trained for 3000 passes through the training corpus ("epochs"), by which time it had learned the corpus (i.e., it could produce the correct semantic representation for each input word form representation). We then created one low-density and one high-density nonword—i.e. one nonword that had 1 CVC neighbor in the corpus of words known by the network (low density),and one nonword that had a higher number of neighbors in the corpus (high-density).

To test the network's mapping of the low- and high-density nonwords, two new vocabularies were created. These differed in the number of neighbors in the vocabulary for the high-density nonword (5 or 10). The network was then trained for 20 exposures on either the hi-density word-semantic representation pairing, or the lo-density word-semantic pairing. At the end of the 20 exposures, we examined the model's total sum-squared (TSS) error in producing the correct semantic output for the high-density and low-density nonwords. We also examined TSS error with respect to "foils" i.e., semantic stimuli that the network had not been trained to associate with either the high- or low-density nonword.

Results

The key finding in the behavioral results was of an interaction such that the effect of high vs. low neighborhood density on toddler's looking times differed for those children with many "wat" neighbors vs. those infants with few "wat" neighbors (see Figure 1). The primary question of interest, therefore, was whether the model would exhibit a similar High/Low x Many/Few interaction. These two independent variables had close analogues in the model. The High/Low variable was represented by the High vs. Low density nonword presented to the model. The Many/Few variable was represented by the manipulation whereby the network had a vocabulary with either many (10) or few (5) neighbors for the high-density nonword. The dependent variable was the difference between the network's TSS error for the target vs. the foil, in each of the four conditions defined by the two independent variables.

Figure 2 shows the difference scores broken down by nonword neighborhood density (High/Low) and number of neighbors for the high density nonword (Many/Few). As shown, the model exhibited the same pattern of interaction as in the behavioral data. A 2-way ANOVA confirmed that the interaction was significant, $F(1,48)=17.544$, $p=0.0001$. Planned comparisons showed that the foil-target difference was significantly greater for the HD than the LD nonword when the network had *Many* neighbors for the high density nonword, $F(1,24)=20.47$, $p=.0001$, but not when the network had *Few* neighbors for the high density nonword, $F(1,24) = 1.53$, $p=.23$.
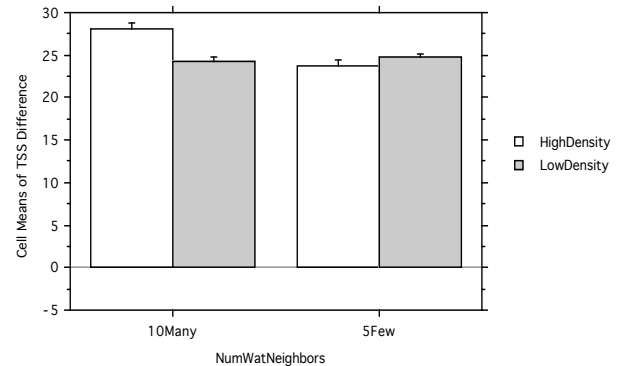

Figure 2: Results from the computational model

Why do these results arise in the model? The semantic activation pattern evoked at the model's output layer by a novel phonological pattern presented at the input layer is an average of the semantic patterns that would be evoked by similar input phonological patterns. For a novel word form that has many similar input phonological patterns, the semantic pattern evoked at the output layer is the average of the set of semantic patterns that would have been evoked by those similar input phonological patterns. The larger the number of similar inputs, the greater the set of semantic patterns that would be evoked, and therefore, the more closely that this average reflects the mean of semantic space. As a result, the model's output response will be nonrandom with respect to semantic space, and therefore fairly different from the semantics of an arbitrarily selected "foil". If there is only one similar

known phonological input, however, the model's output response is relatively random with respect to semantic space, and therefore will not be very different from an arbitrarily selected foil. Thus the distance between the model's semantic response to an input phonological pattern and an arbitrarily selected semantic pattern (i.e., a "foil") is inversely proportional to the number of previously known similar input phonological patterns. When there are 5 previously known similar input patterns, this distance is not significantly greater than when there is only one similar previously known input. However, when there are 10 previously known similar inputs, the divergence is substantial. This is what gives rise to the pattern shown in Figure 2.

General Discussion

The experimental results demonstrated that children find it easier to learn words that have large numbers of neighbors. This suggests that, as children learn new words, their ability to acquire subsequent words will change. The connectionist model shows a similar pattern of behavior, demonstrating an advantage for high-density words only after those words have a sufficient number of lexical neighbors. While it would be premature to draw conclusions regarding the mechanistic basis of the behavioral result obtained in infants, the model does enable mechanistic understanding of the similar behavioral effect in the model. While more investigation is needed, we regard this as a useful first step towards understanding the behavioral results described above.

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