Whole-Word versus Part-Word Phonotactic Probability/Neighborhood Density in Word Learning by Children

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1. Introduction

To learn a word, children need to acquire three types of representations: phonological, lexical, and semantic. The *phonological representation* consists of the individual sounds in the word, such as /b/, /i/, and /n/ for 'bean.' The *lexical representation* consists of the sounds of the word as a whole unit, such as /bin/ for 'bean.' Thus, the phonological and lexical representations store information in long-term memory about the form characteristics of a word. The difference between the two is that the phonological representation relates to the individual components of the form, whereas the lexical representation relates to the entire form as an integrated unit. In contrast, the *semantic representation* consists of information about the meaning or referent of the word. For example, the semantic representation of 'bean' would contain information such as 'legume' and 'kidney-shaped.' All three representations are needed for both comprehension and production of a word. In this paper, we focus on the phonological and lexical characteristics of words that may influence the speed of word learning.

One phonological characteristic that has been shown to influence spoken language processing is phonotactic probability. *Phonotactic probability* is the likelihood of occurrence of a sound sequence in a given language (Vitevitch & Luce, 1999). Children and adults tend to recognize and produce high probability sound sequences more rapidly and accurately than low probability sound sequences (e.g., Edwards, Beckman, & Munson, 2004; Munson, Swenson, & Manthei, 2005; Vitevitch, Armbruster, & Chu, 2004; Vitevitch & Luce, 1999).

Turning to lexical characteristics, *neighborhood density* refers to the number of words that are phonologically similar to a given word, differing by only one phoneme (Luce & Pisoni, 1998). Children and adults tend to recognize high density words more slowly and less accurately than low density words (e.g., Garlock, Walley, & Metsala, 2001; Luce & Pisoni, 1998). In contrast, children and adults tend to produce high density words more rapidly and accurately than low density words (e.g., German & Newman, 2004; Vitevitch, 1997; Vitevitch, 2002b).

Taken together, phonotactic probability and neighborhood density appear to influence spoken language processing by adults and children. Moreover, Past studies provide evidence that the phonotactic probability and neighborhood

 BUCLD 30 Proceedings, ed. D. Bamman, T. Magnitskaia, and C. Zaller, 584-594. Somerville, MA: Cascadilla Press.

density of a novel word influence word learning by children. Specifically, a series of studies by Storkel and colleagues have examined learning of high phonotactic probability/high neighborhood density novel words compared to learning of low phonotactic probability/low neighborhood density novel words (Storkel, 2001, 2003; Storkel & Maekawa, 2005; Storkel & Rogers, 2000). Results showed that preschool and school-age children learned high probability/high density novel words more rapidly than low probability/low density novel words.

Previous studies of word learning have only examined the influence of the phonotactic probability/neighborhood density of the *whole* word. However, emerging evidence suggests that the phonotactic probability/neighborhood density of *parts* of words also may influence spoken language processing. For example, Vitevitch and colleagues provide evidence that words with the same overall number of neighbors, can differ in the number of neighbors that share a particular part of the word (Vitevitch, 2002a; Vitevitch et al., 2004). That is, two words having the same number of neighbors may differ in the distribution of those neighbors. For example, the majority of neighbors for one word may share the onset or word-initial sound (e.g., '*m*ass' and '*m*ad') whereas only a minority of neighbors for another word may share the onset. Thus, the first word would be said to have a higher onset density, or more onset neighbors, than the second word. When the overall number of neighbors is held constant, adults recognize words with many onset neighbors more slowly than words with few onset neighbors (Vitevitch, 2002a) and produce words with many onset neighbors more quickly than words with few onset neighbors (Vitevitch et al., 2004). Taken together, part-word neighborhood density appears to influence spoken language processing by adults.

It is important to note that in these past studies, the number of other types of neighbors also varied. Specifically, if the overall number of neighbors is held constant and a word has few onset neighbors, it must have a large number of neighbors of another type. One other type of neighbor is a *rhyme neighbor*, namely a word that shares the vowel and coda or word-final consonant (e.g., 'm*ass*' and 'b*ass*'). The goal of the current study was to determine whether part-word phonotactic probability/neighborhood density influenced word learning by manipulating the phonotactic probability/neighborhood density of the initial consonant-vowel (CV) and the vowel-final consonant (VC) of consonant-vowel-consonant (CVC) nonwords. This simultaneous manipulation of CV phonotactic probability/neighborhood density and VC phonotactic probability/neighborhood density also resulted in changes in whole-word phonotactic probability/neighborhood density. This allowed a comparison of the influence of part-word versus whole-word phonotactic probability/neighborhood density on word learning.

An additional goal of the current study was to examine whether the effect of part-word phonotactic probability/neighborhood density on word learning varied by age. Some previous studies of similarity classification suggest that young children recognize overall similarity between words, whereas older children classify words based on similarity of parts (e.g., Treiman & Breaux, 1982; Walley, Smith, & Jusczyk, 1986), although this is not without controversy (e.g., Gerken, Murphy, & Aslin, 1995; Swingley & Aslin, 2000, 2002). Moreover, in the emergence of awareness of similarity there appears to be an asymmetry in awareness of specific parts of words. Specifically, some studies suggest that children first recognize similarity in the onset rather than the rhyme (e.g., Jusczyk, Goodman, & Baumann, 1999; Swingley, Pinto, & Fernald, 1999; Walley et al., 1986), whereas other studies indicate that children first recognize similarity in the rhyme rather than the onset (e.g., Treiman & Zukowski, 1991; Treiman & Zukowski, 1996). This suggests that the influence of part-word phonotactic probability/neighborhood density on word learning may increase with age.

2. Method
2.1 Participants

To date, data have been collected from 43 monolingual English-speaking typically developing children. Children were divided into two groups based on age: a younger group of 20 3-year-old children (*M* = 3 years; 6 months; *SD* = 3 months; range 2; 11 to 3; 11) and an older group of 23 4- and 5-year-old children (*M* = 4 years; 8 months; *SD* = 5 months; range 4; 0 to 5; 6). All children obtained scores above one standard deviation below the mean on standardized tests of phonology, expressive vocabulary, and receptive vocabulary (Brownell, 2000a, 2000b; Goldman & Fristoe, 2000).

2.2 Stimuli

Phonotactic probability and neighborhood density were computed for all legal CVC nonwords in English. Both measures were computed using previously published procedures and a previously described 20,000 word adult database (Storkel, 2004b). Biphone frequency was used as a measure of phonotactic probability. *Biphone frequency* was computed by searching the 20,000 word database for all the words that contained a given biphone in a given word position and summing the log frequency of those words. This sum was then divided by the sum of the log frequency of all of the words in the database that contained any biphone in the same word position. Biphone frequency was computed for the CV and VC, constituting the part-word phonotactic probability. The CV and VC biphone frequency were then summed to measure the whole-word phonotactic probability.

For neighborhood density, whole-word neighborhood density was computed first by searching the 20,000 word database to identify all the words that differed from a given CVC by only one phoneme. The number of different words was counted, yielding the whole-word neighborhood density. Individual neighbors were then categorized as sharing the CV, VC, or C_C. The number of CV and VC neighbors was counted, yielding the part-word neighborhood density.

Selected nonword stimuli consisted of 16 CVCs varying in part-word phonotactic probability/neighborhood density with 4 CVCs in each of the following part-word conditions: (1) Low CV/Low VC phonotactic probability/neighborhood density; (2) Low CV/High VC; (3) High CV/Low VC; (4) High CV/High VC. Table 1 shows the part-word phonotactic probability and neighborhood density for each condition.

Whole-word phonotactic probability/neighborhood density also varied across these four part-word conditions with (1) Low CV/Low VC nonwords having the lowest whole-word phonotactic probability/neighborhood density; (2) Low CV/High VC and High CV/Low VC having an equivalent, medium whole-word phonotactic probability/neighborhood density; (3) High CV/High VC having the highest whole-word phonotactic probability/neighborhood density. Table 1 shows the whole-word phonotactic probability and neighborhood density for the four part-word conditions.

Table 1. Mean (and standard deviation) part-word and whole-word phonotactic probability and neighborhood density of the selected CVCs.

	Low CV/ Low VC	Low CV/ High VC	High CV/ Low VC	High CV/ High VC
		Phonotactic Probability		
CV	0.0004	0.0004	0.0046	0.0061
	(0.0003)	(0.0003)	(0.0031)	(0.0042)
VC	0.0004	0.0030	0.0005	0.0057
	(0.0003)	(0.0015)	(0.0003)	(0.0062)
Whole-word	0.0008	0.0034	0.0050	0.0118
	(0.0003)	(0.0018)	(0.0031)	(0.0052)
		Neighborhood Density		
CV	2	1	8	8
	(1)	(1)	(2)	(2)
VC	1	8	1	10
	(1)	(2)	(1)	(2)
Whole-word	4	11	11	21
	(1)	(2)	(3)	(3)

The 16 CVC nonwords were paired with unusual objects that were created or adapted from children's stories. These objects were difficult for adults to name with one word. The objects were selected in quadruplets from the same semantic category so that semantic and conceptual factors could be controlled across the four part-word conditions described above. These objects are described more extensively in Storkel (2004a). The pairing of nonwords and objects was counterbalanced across participants

The 16 nonword-object pairs were divided into two sets of eight, with two nonwords from each of the four conditions in each set. Each set of eight nonword-object pairs were embedded in a story. Each story contained three episodes. Each episode showed two main characters performing a familiar task (e.g., hiding objects) with the eight objects. A narrative accompanied the visual scenes, providing exposure to the nonword that was paired with each object. Following completion of each story episode, the nonword-object pairs were reviewed one-by-one. Each episode and review provided 8 exposures to each nonword-object pair for a total of 24 exposures at the completion of the story. The story used is similar to that described in Storkel (2004a).

Learning was measured in a picture-naming task prior to the beginning of each story, following each story episode and review, and one week after listening to the story. In the picture-naming task, a picture of each object was presented and children attempted to name the object using the nonword from the story. Responses were audio-recorded, phonetically transcribed and scored for accuracy. A response was scored as correct if it contained two of the three target phonemes in the target word position.

2.3 Procedure

Each child participated in four sessions. During the first session, a standardized phonology test, a specially constructed phonology probe, and a hearing screening were administered (ASHA, 1997; Goldman & Fristoe, 2000). The second session consisted of administration of the first story. Children were seated in front of a laptop computer connected to table-top speakers set at a comfortable listening level. Children also wore a head-mounted microphone connected to a digital audio tape recorder. The session began with baseline testing in the picture-naming task. Administration of this task was controlled by Direct RT software (Jarvis, 2002). Pictures were randomly presented on the laptop, and children were encouraged to guess their names. Following baseline testing, the first episode and review were administered. Presentation of visual scenes and accompanying auditory narratives again was controlled by Direct RT software. Following administration of the first episode and review, the picture-naming task was re-administered with children being encouraged to remember the names of the objects from the story. This pattern was repeated for the remaining two episodes and reviews. The third session occurred approximately 1-week after the second. Recall of the items presented in the second session was tested using the picture-naming task. The second story was then administered following the same procedures as the first story. Children returned for a fourth session approximately 1-week later so that recall of the items from the third session could be tested. In addition, standardized vocabulary tests were administered (Brownell, 2000a, 2000b).

3. Results

Proportion correct in the picture-naming task at the 1-week recall test was submitted to a 2 CV phonotactic probability/neighborhood density (low vs.

high) x 2 VC phonotactic probability/neighborhood density (low vs. high) x 2 age (3 vs. 4/5) mixed analysis of variance. The two-way interaction of CV phonotactic probability/neighborhood density and VC phonotactic probability/neighborhood density was significant, F (1, 41) = 4.16, $p < .05$, $\eta_p^2 = .09$. Moreover, the three-way interaction of CV phonotactic probability/neighborhood density, VC phonotactic probability/neighborhood density, and age was significant, F (1, 41) = 6.14, $p < .02$, $\eta_p^2 = .13$. No other main effects or interactions were significant, $F < 3.50$, $p > .07$, $\eta_p^2 < .08$.

The significant three-way interaction was investigated further by analyzing the data from each age group separately, using a 2 CV phonotactic probability/neighborhood density (low vs. high) x 2 VC phonotactic probability/neighborhood density (low vs. high) repeated measures analysis of variance.

For the 3-year-old group, there was a significant interaction between CV phonotactic probability/neighborhood density and VC phonotactic probability/neighborhood density, F (1, 19) = 11.07, $p < .01$, $\eta_p^2 = .37$. The main effects were not significant, $F < 0.39$, $p > .50$, $\eta_p^2 < .03$. Figure 1 shows the proportion correct for the 3-year-old children in each of the four part-word phonotactic probability/neighborhood density conditions. The part-word phonotactic probability/neighborhood density conditions are arranged from lowest to highest whole-word phonotactic probability/neighborhood density.

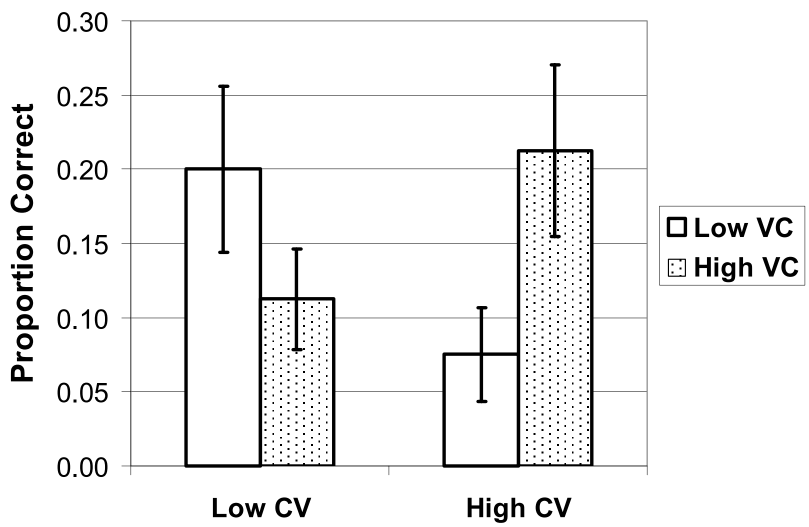

Figure 1. Proportion correct for 3-year-old children for low versus high CV phonotactic probability/neighborhood density (x-axis) and low (open bar) versus high (filled bar) VC phonotactic probability/neighborhood density.

From this figure, 3-year-old children showed the highest proportion correct for nonwords in the Low CV/Low VC and High CV/High VC conditions. In contrast, the lowest proportion correct for 3-year-old children was observed in the Low CV/High VC and High CV/Low VC conditions. Thus, there is no clear advantage for either CV or VC part-word phonotactic probability/neighborhood density. However, the results appear more interpretable when whole-word phonotactic probability/neighborhood density is examined. Specifically, highest accuracy was observed for lowest whole-word phonotactic probability/neighborhood density (i.e., Low CV/Low VC) and highest whole-word phonotactic probability/neighborhood density (i.e., High CV/High VC). In contrast, lowest accuracy was observed for mid whole-word phonotactic probability/neighborhood density (i.e., Low CV/High VC and High CV/Low VC). Taken together, 3-year-old children showed a U-shaped effect of whole-word phonotactic probability/neighborhood density on word learning.

For the 4-/5-year-old group, there was a significant main effect of VC phonotactic probability/neighborhood density, F (1, 22) = 4.97, $p < .05$, $\eta_p^2 = .18$. The remaining main effect and interaction were not significant, $F < 0.10$, $p > .75$, $\eta_p^2 < .01$. Figure 2 shows the proportion correct for the 4-/5-year-old children in each of the four part-word phonotactic probability/neighborhood density conditions.

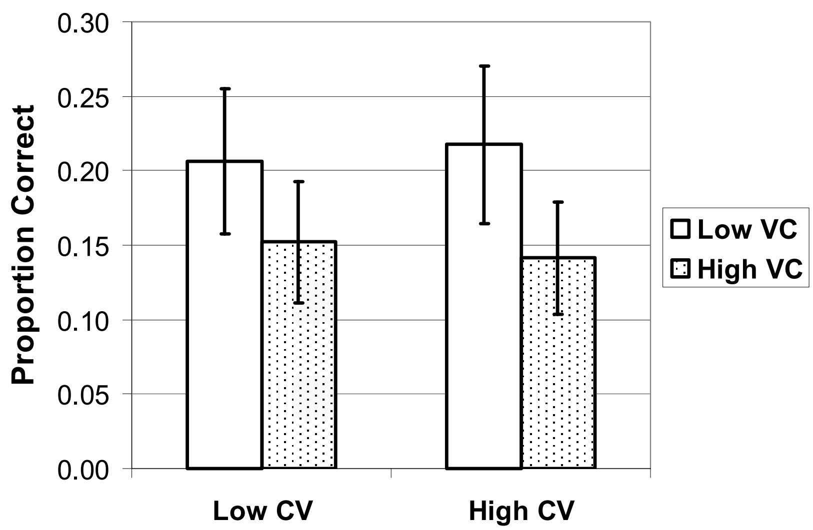

Figure 2. Proportion correct for 4- and 5-year-old children for low versus high CV phonotactic probability/neighborhood density (x-axis) and low (open bar) versus high (filled bar) VC phonotactic probability/neighborhood density.

According to this figure, 4- and 5-year-old children showed the highest proportion correct for nonwords with low VC phonotactic probability/neighborhood density (open bars), regardless of the CV phonotactic probability/neighborhood density or the whole-word phonotactic probability/neighborhood density. In contrast, the lowest proportion correct was observed for nonwords with high VC phonotactic probability/neighborhood density (filled bars), regardless of the CV phonotactic probability/neighborhood density or the whole-word phonotactic probability/neighborhood density. Thus, 4- and 5-year-old children showed a clear effect of part-word phonotactic probability/neighborhood density that was attributable to the VC (i.e., rhyme).

4. Discussion

The goal of this study was to determine whether part-word phonotactic probability/neighborhood density influenced word learning by younger and older children. Results showed that word learning by 3-year-old children was influenced by whole-word phonotactic probability/neighborhood density, whereas word learning by 4- and 5-year-old children was influenced by part-word phonotactic probability/neighborhood density, specifically VC (i.e., rhyme) phonotactic probability/neighborhood density. This finding further supports the hypothesis that processing shifts from holistic to fine-grained with development and extends this hypothesis to word learning. This shift in the influence from whole-words to part-words in word learning may coincide with or precede the emergence of phonological awareness, an important pre-reading skill. Further research is needed to examine the influence and awareness of whole-words versus part-words across ages and across processing tasks to better understand the mechanisms that drive this processing shift.

An additional note-worthy finding of this study is the U-shaped pattern observed for the influence of whole-word phonotactic probability/neighborhood density on word learning by 3-year-old children. In terms of comparison to past studies of whole-word phonotactic probability/neighborhood density, the values for "low" in this study were comparable to "low" in past studies (Storkel, 2001, 2003; Storkel & Maekawa, 2005; Storkel & Rogers, 2000). The values for "mid" in this study were comparable to "high" in previous studies (Storkel, 2001, 2003; Storkel & Maekawa, 2005; Storkel & Rogers, 2000). In contrast, the "high" values in this study have not been previously examined in studies of word learning.

The findings from the current study suggest that there is an advantage for low and high phonotactic probability/neighborhood density. This may be explained by assuming complementary mechanisms in word learning. Specifically, low phonotactic probability/neighborhood density may be advantageous because the novel word will stand out as being unique from other sound sequences in the language. In this case, the child may rapidly recognize that the word is new. Consequently, learning of the new word may be immediately initiated following just one exposure. Thus, fewer exposures may be needed to fully learn the new word. In contrast, high phonotactic probability/neighborhood density may be advantageous because the sound sequence is more cohesive and predictable. Therefore, the novel sound sequence is held in working memory more easily, facilitating the creation of a new lexical representation. Finally, sound sequences with mid phonotactic probability/neighborhood density are neither unique nor cohesive, resulting in poorer learning.

The findings from the 4- and 5-year-old children also can be interpreted within the framework presented for the 3-year-old children. Specifically, 4- and 5-year-old children learned nonwords with low rhyme phonotactic probability/neighborhood density more readily than nonwords with high rhyme phonotactic probability/neighborhood density. These older children have shifted from whole-word to part-word phonotactic probability/neighborhood density, but continue to show an advantage for unique sound sequences, as hypothesized for the 3-year-old children.

Taken together, the findings suggest that part-word phonotactic probability/neighborhood density does influence word learning by preschool children, but only in older preschool children, indicating a shift from holistic to fine-grained processing in word learning. The emergence of the influence of part-word phonotactic probability/neighborhood density may be an important milestone in development, although this hypothesis warrants further investigation.

5. Acknowledgements

This research was supported by DC04781; DC00052; DC 05803; HD02528. The following research assistants contributed to study preparation, data collection, and data processing: Teresa Brown, Jennie Fox, Andrea Giles, Stephanie Gonzales, Junko Maekawa, Mariza Rosales, Katherine Shatzer, Maki Sueto, Courtney Winn, and Allison Wade. Address correspondence to Holly L. Storkel, Speech-Language-Hearing Department, University of Kansas, 1000 Sunnyside Ave., 3001 Dole Human Development Center, Lawrence, KS 66045-7555, USA. E-mail: hstorkel@ku.edu. Website: www.ku.edu/~wrdlrng/.

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