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Phonotactics, Neighborhood Activation, and Lexical Access for Spoken Words

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Abstract

Probabilistic phonotactics refers to the relative frequencies of segments and sequences of segments in spoken words. *Neighborhood density* refers to the number of words that are phonologically similar to a given word. Despite a positive correlation between phonotactic probability and neighborhood density, nonsense words with high probability segments and sequences are responded to more *quickly* than nonsense words with low probability segments and sequences, whereas real words occurring in dense similarity neighborhoods are responded to more *slowly* than real words occurring in sparse similarity neighborhoods. This contradiction may be resolved by hypothesizing that effects of probabilistic phonotactics have a sublexical focus and that effects of similarity neighborhood density have a lexical focus. The implications of this hypothesis for models of spoken word recognition are discussed.

Keywords

spoken word recognition; probabilistic phonotactics; neighborhood activation

Probabilistic phonotactics refers to the frequency that a particular segment or sequence of segments will occur in a given position in a word or syllable (Treiman, Kessler, Knewasser, Tincoff, & Bowman, 1996; Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997). Recent work (Vitevitch et al., 1997; Vitevitch & Luce, 1998; 1999) has shown that probabilistic phonotactic information has demonstrable effects on spoken word recognition.Vitevitch et al. (1997) found that subjective ratings as well as response times in an auditory naming task coincide with the objective measures of phonotactic probability. High probability nonwords were rated more word-like (see also Eukel, 1980) and were repeated faster than low probability nonwords. These results suggest that probabilistic phonotactic information is not only represented in memory, but that it influences the processing of spoken stimuli.

Common segments and sequences found in spoken words with high phonotactic probabilities are, by definition, those segments and sequences found in many words. A word

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(or nonword) containing frequently occurring segments and sequences is often phonologically similar to many other words. That is, high probability phonotactic patterns typically occur in *dense phonological neighborhoods.* Conversely, low probability phonotactic patterns typically occur in *sparse phonological neighborhoods.* In short, there is a positive correlation between phonotactic probability and neighborhood density.[1]

Work by Luce and Pisoni (1998) on the neighborhood activation model (NAM) has demonstrated that neighborhood density affects the speed and accuracy of spoken word recognition. According to NAM, spoken words are recognized in the context of phonologically similar words activated in memory. Stimulus input (i.e., a spoken word) activates a set or neighborhood of similar sounding words in memory, which then compete for recognition. According to NAM, greater lexical competition results in slower and less accurate processing. Thus, NAM predicts that words in high-density phonological neighborhoods will be responded to less quickly and accurately than words occurring in low-density neighborhoods. Stated in terms of probabilistic phonotactics, the model predicts that words that share fewer segments and sequences of segments will be responded to more quickly than words that share many segments and sequences of segments.

Numerous studies (Cluff & Luce, 1990; Goldinger, Luce, & Pisoni, 1989; Luce, Goldinger, Auer, & Vitevitch, in press; Luce & Pisoni, 1998) have confirmed the predictions of NAM. For example, in perceptual identification tasks, words with low-density neighborhoods are identified in noise more accurately than words with high-density neighborhoods. In auditory naming and lexical decision tasks, words with low-density neighborhoods are responded to more quickly than words with high-density neighborhoods.

Despite the previous success of NAM in predicting recognition speed and accuracy for real words, the model makes an erroneous prediction regarding the effects of phonotactic probability on the processing of nonsense words. Given the correlation between neighborhood density and segment frequency, NAM predicts that the competition among the words activated in memory should result in nonwords with high phonotactic probability being repeated more slowly than nonwords with low probability. However, the results obtained byVitevitch et al. (1997)—who found that high probability nonwords were responded to more, rather than less, quickly—contradict the predictions of NAM.

The key to the discrepancy between the Vitevitch et al. results and NAM's predictions appears to lie in the lexicality of the stimulus under scrutiny. In particular, NAM correctly predicts the speed and ease of recognizing words but not nonwords. The observation that effects of probabilistic phonotactics and similarity neighborhood density vary with lexicality led us to propose that effects of probabilistic phonotactics have a sublexical focus, whereas effects of similarity neighborhood density have a lexical focus. In other words, we propose that inhibitory effects of similarity neighborhood density on real words result from lexical competition. Facilitative effects of probabilistic phonotactics for nonwords arise because nonwords fail to strongly activate competing lexical representations. Processing of high probability nonwords thus benefits from the *presence* of high frequency segments and sequences and the *absence* of strong lexical competition.

To explore further how sublexical and lexical levels of representation might influence spoken word recognition, Vitevitch and Luce (1998; 1999) carried out several experiments using words and nonwords that varied simultaneously in phonotactic probability and neighborhood density (i.e., the number of real words similar to the stimulus item). Stimuli

[1]The results of an analysis of 1041 consonant–vowel–consonant content words show that the neighborhood density and the sum of the frequency for the segments in each word were highly correlated ($r = .61$, $p < .0001$).

were selected that fell into one of four conditions: (1) high density–high phonotactic probability words, (2) low density–low phonotactic probability words, (3) high density–high phonotactic probability nonwords, and (4) low density–low phonotactic probability nonwords. When *words* were presented in an auditory naming task (Vitevitch & Luce, 1998), inhibitory effects of neighborhood density were observed: High probability–density words were repeated more slowly than low probability–density words. However, when *nonwords* of varying phonotactic probability and neighborhood density were presented in the same task, the opposite pattern was obtained: High probability–density nonwords were repeated more quickly than low probability–density nonwords. These results confirm our hypothesis that effects of similarity neighborhood density are inhibitory and have a lexical focus whereas effects of probabilistic phonotactics are facilitative and have a sublexical focus. Further work has demonstrated that the observed dissociation of probabilistic phonotactics and density as a function of lexicality is a robust phenomenon that is replicable across a variety of experimental tasks.

To garner further evidence for the operation of two levels of representation and processing, we attempted to: (1) bias the processing of nonwords toward the lexical level by using an auditory lexical decision task and, (2) bias the processing of words toward the sublexical level by using an auditory same– different task. If effects of similarity neighborhood density and probabilistic phonotactics have loci at different levels of processing, encouraging processing of nonwords at a lexical level should reveal effects of neighborhood competition (where previously we had only observed facilitative effects of phonotactics). To this end, Vitevitch and Luce (1999) presented words and nonwords varying on phonotactic probability and density in an auditory lexical decision task. In this task, participants were presented with a stimulus on each trial and had to decide on its lexical status. The auditory lexical decision task thus necessitated the activation of lexical items in memory to categorize the stimulus successfully as a word or nonword, even when the stimulus was a nonword. To make a lexical decision on a nonword, one had to activate representations at a lexical level (at least for the types of phonotactically legal nonwords employed in our experiments). Thus, Vitevitch and Luce predicted that the same nonwords that previously showed facilitative effects of probabilistic phonotactics in the naming and same–different tasks would show neighborhood density effects in the auditory lexical decision task. Their predictions were borne out: words and nonwords with high probability phonotactics and neighborhood density were responded to more slowly than words and nonwords with low probability phonotactics and neighborhood density.

Vitevitch and Luce (1999) were also interested in determining if the effects of neighborhood density so pervasive for words could be modified by focusing participants' processing on a sublexical level. They again presented words and nonwords varying in phonotactic probability and neighborhood density in a same–different task. In the previous experiment using this task, Vitevitch and Luce presented the words and nonwords blocked. That is, participants heard a list containing only words or a list containing only nonwords. They reasoned that if the presentation of words and nonwords was mixed, participants would focus their processing on the one level common to all of the stimuli, namely the sublexical level. Although we did not predict that the words would actually show a reversal of the density effect in favor of probabilistic phonotactics (owing to the overwhelming dominance of the lexical level in normal spoken language processing), we nonetheless predicted an attenuation of the effect of similarity neighborhood competition. Again, our predictions were borne out: High phonotactic probability nonwords once again showed facilitative effects. However, the effects of similarity neighborhood competition previously observed for these same word stimuli were now considerably attenuated, resulting in no significant effect of neighborhood density for the words.

Density effects for words may indeed be reversed in favor of probabilistic phonotactic effects if similarity neighborhood competition can be *minimized* by controlling the neighborhood density of the words while varying their phonotactic probability. Using stimuli of this type, Luce and Gaygen (1998) found such a reversal in an auditory naming task: *words* with high-probability phonotactics were repeated *more quickly* than words with low-probability phonotactics. These results further suggest that two levels of representation may be used to process not only nonwords but real words as well.

Our work on phonotactics and neighborhood activation suggests the operation of two levels of representation and process in spoken word recognition. One level is a sublexical level, consisting of facilitative activation among segments and sequences of segments. The other level is a lexical level, consisting of competitive interactions among multiple word forms. Models of spoken word recognition, such as NAM (Luce & Pisoni, 1998) and cohort theory (Marslen-Wilson, 1987; Marslen-Wilson & Tyler, 1980), which lack a sublexical level of representation, are unable to account for these effects. However, Shortlist (Norris, 1994) and a more recent connectionist version of NAM, called PARSYN (Auer & Luce, 1998; Luce et al., in press), which have two levels of representation and processing, may more accurately account for spoken word recognition effects as a function of neighborhood activation and probabilistic phonotactics.

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