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**Tongue Twisters Reveal Neighborhood Density Effects  
in Speech Production<sup>1</sup>**

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## Tongue Twisters Reveal Neighborhood Density Effects in Speech Production

**Abstract.** The influence of similarity neighborhoods on speech production was investigated by experimentally eliciting speech errors with a tongue twister task. Half of the tongue twisters consisted of words from lexically dense neighborhoods, whereas the other half of the tongue twisters consisted of words from lexically sparse neighborhoods. The results showed that more erroneous repetitions were made on tongue twisters containing words from sparse neighborhoods than on tongue twisters containing words from dense neighborhoods. The implications of these findings for models of speech production and for models of word recognition are discussed.

A *phonological similarity neighborhood* refers to a group of similar sounding words that are confuseable with one another (Landauer & Streeter, 1973; Luce, 1986; Luce and Pisoni, 1998). One metric used to assess similarity is the addition, deletion, or substitution of a single phoneme (Greenberg & Jenkins, 1964). A number of studies have demonstrated that individual words differ in terms of neighborhood size, and that this difference has consequences on perception (Luce, 1986; Luce and Pisoni, 1998). That is, some words have many similar sounding words (i.e., a dense neighborhood), whereas other words have few similar sounding words (i.e., a sparse neighborhood). Words with dense neighborhoods are recognized more slowly and less accurately than words with sparse neighborhoods (Luce, 1986; Luce and Pisoni, 1998).

A number of other variables, including word frequency (Howes, 1957; Newbigging, 1961; Savin, 1963; Solomon & Postman, 1952), phonotactic information (Vitevitch, 1997a; Vitevitch & Luce, in press; Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997), and semantic information (Swinney, 1979), affect the speed and accuracy with which spoken words are recognized. Other studies have demonstrated that these variables also affect the speed and accuracy with which spoken words are *produced* (see Dell, 1988, 1990; Jescheniak & Levelt, 1994; Oldfield & Wingfield, 1965, for frequency effects; see Motley, 1973; and Motley & Baars, 1975, for phonotactic effects; see Motley and Baars, 1976a for a semantic effect). Little work, however, has investigated the influence of phonological similarity neighborhoods on speech production.

An earlier experiment by Goldinger and Summers (1989) demonstrated that neighborhood density influenced the voice onset time (VOT) for spoken words. They presented participants with word pairs of varying neighborhood density that differed in the voicing of the initial consonants (e.g., *dutch-touch*). They found that the differences in VOT between the first word and the second word of the pairs were larger for word pairs with dense neighborhoods than for word pairs with sparse neighborhoods. These differences became smaller for sparse neighborhood word pairs across sessions, but became larger for dense neighborhood word pairs across sessions.

Goldinger and Summers also found that the interword interval, or the time between the offset of the first word and the onset of the second word within each minimal pair, was greater for dense neighborhood word pairs than for sparse neighborhood word pairs. These results suggest that neighborhood density also affects the rate of speech production in demonstrable ways (see also Wright, 1998).

However, a regression analysis of reaction times from a picture naming task by Jescheniak and Levelt (1994) failed to find an effect of the number of words similar to a lexical item (as measured by the

cohort count; Marslen-Wilson and Welsh, 1978; and as measured by the Coltheart-*N*; Coltheart, Davelaar, Jonasson, and Besner, 1977) on the rate of speech production. Because phonological similarity was not specifically manipulated in the Jescheniak and Levelt experiments, it is very likely that their posthoc analysis may have been insensitive to the influences of phonological similarity on speech production.

Although the results showing an influence of neighborhood density on the *speed* of speech production are not consistent, a study by Vitevitch (1997b) demonstrated a reliable influence of neighborhood density on the *accuracy* of speech production. Vitevitch analyzed the lexical characteristics of a corpus of malapropisms, or phonologically-based speech errors involving whole words (e.g., saying *monotony* instead of *monogamy*). The results from that investigation showed that malapropisms tend to have sparser neighborhoods than “control” words of equal length (in terms of number of phonemes) that were randomly selected from the lexicon. This corpus analysis suggests that neighborhood density has demonstrable effects on the *accuracy* with which a spoken word is produced.

However, several concerns have been raised regarding the use of data from speech error corpora. Specifically, Cutler (1982) and others (Ferber, 1991; MacKay, 1980; Mowrey and MacKay, 1990; Stemberger, 1992) have suggested that perceptual biases may distort what is perceived and recorded as a speech error, thereby disproportionately skewing the lexical characteristics of speech error corpora.

In order to avoid some of the potential sampling problems of speech error corpora, Stemberger (1992) has suggested that speech production findings be replicated either by examining multiple error corpora or by eliciting speech errors experimentally (see Baars, 1992; Motley & Baars, 1976b). Replication via experimentally eliciting speech errors offers several advantages over investigations of naturalistic error corpora.

Experimentally eliciting speech errors allows one to reduce the possibility of spurious effects resulting from perceptual biases by recording and carefully analyzing the experimental sessions. In addition, one can more precisely calculate actual error probabilities (Motley & Baars, 1976b), rather than estimate error probabilities from naturalistic error corpora. Finally, experimentally eliciting speech errors allows one to carefully examine and manipulate selected experimental variables.

To further investigate the influence of similarity neighborhoods on speech production, a tongue twister task—a task which elicits errors involving phonological segments rather than whole words (Baars, 1992)—was used to obtain speech errors on words of varying neighborhood density. Based on the findings involving a corpus of malapropisms (Vitevitch, 1997a), we would anticipate more errors involving phonological segments among tongue twisters containing words with sparse neighborhoods than among tongue twisters containing words with dense neighborhoods.

Because phonological errors occur at a different level of representation (i.e., a sub-lexical level) than whole-word malapropisms, which occur at a lexical or word-form level (Garrett, 1988; Levelt et al., 1991), it is also possible that a different pattern of errors may result. Thus, more errors involving phonological segments might occur among tongue twisters consisting of words with dense neighborhoods than among tongue twisters consisting of words with sparse neighborhoods. Because the goal of the present investigation is to examine empirically *if* similarity neighborhoods affect speech production, either outcome is acceptable.

## Methods

### Participants

Twenty-eight native English speakers from the Indiana University pool of Introductory Psychology students participated in partial fulfillment of a course requirement. All participants reported no history of a speech or hearing problem at the time of testing.

### Stimuli

Ten pairs of highly confuseable target segments (those used in Experiment 2 of Shattuck-Hufnagel, 1992) were used to select CVC words for the tongue twisters used in this experiment. That is, only words that had the same initial segments as those in Experiment 2 of Shattuck-Hufnagel (1992) were considered in the selection of stimuli. (Two pairs of segments in Shattuck-Hufnagel (1992) were not used in the current experiment because a sufficient number of words with the desired characteristics could not be found in each condition.) Twenty tongue twisters, each containing four words, were created. Half of the tongue twisters were comprised of words with sparse neighborhoods, and the other half of the tongue twisters were comprised of words with dense neighborhoods.

Neighborhood density is defined as the number of words that are similar to the target item. Similarity is assessed by adding, deleting, or substituting one phoneme to the target word. The number of words found in an on-line version of the Webster's Pocket Dictionary, which contains nearly 20,000 words in a computer readable phonetic transcription, constituted the lexical neighborhood of a word.

Words from dense neighborhoods were items that had many similar sounding words found in the lexicon. The mean number of words in a neighborhood for items in the dense neighborhood condition was 23.9 words. Words from sparse neighborhoods were items that had few similar sounding words found in the lexicon. The mean number of words in a neighborhood for items in the sparse neighborhood condition was 15.4 words. The difference between the dense neighborhood and sparse neighborhood condition was highly significant ( $F(1,78) = 143.20, p < .0001$ ).

Although the stimuli differed in neighborhood density, the words used in the sparse neighborhood tongue twisters and the dense neighborhood tongue twisters did not differ in log-frequency ( $F(1,78) = 2.08, p = .15$ ) as measured by the Kucera & Francis (1967) word counts. The mean log-frequency of the items in the dense neighborhood tongue twisters was .83 occurrences per million, and the mean log-frequency of the items in the sparse neighborhood tongue twisters was 1.03 occurrences per million.

The two groups of words also did not differ in neighborhood log-frequency ( $F(1,78) = 1.29, p = .25$ ). Neighborhood log-frequency is defined as the mean log-frequency of the words comprising the neighborhood (also assessed by counts from Kucera & Francis, 1967). The mean neighborhood log-frequency of the items in the dense neighborhood tongue twisters was 1.21 occurrences per million, and the mean log-frequency of the items in the sparse neighborhood tongue twisters was 1.15 occurrences per million. A complete listing of all the stimulus items is given in the appendix.

Finally, the words in each condition were also equivalent in familiarity ratings on a seven point scale. The scale ranged from (1) "don't know the word," to (4) "recognize the word, but don't know the meaning," to (7) "know the word" (Nusbaum, Pisoni, and Davis, 1984). The mean familiarity rating for items in the dense neighborhood tongue twisters was 6.69, and the mean familiarity rating for items in the

sparse neighborhood tongue twisters was 6.80 ( $F(1,78) = 1.20, p = .27$ ). Mean familiarity ratings above 5 ensured that almost all of the participants would be familiar with the words used in the tongue twisters.

### Procedure

Participants were seated individually in a sound proof booth (IAC model 402) equipped with a CRT and a head-mounted microphone. The computer presented a prompt ("Please repeat the following words six times in a row.") and then randomly presented one tongue twister on the CRT for twelve seconds. Participants were instructed to repeat the tongue twister six times as *quickly* as they could. The tongue twister remained on the CRT for the entire duration. Responses were recorded on high quality audiotape for later analysis. At the end of twelve seconds, the prompt was flashed on the CRT and a new trial began.

A practice session of five pseudo-tongue twisters (i.e., four randomly selected words from the items that did not have an initial consonant which matched the Shattuck-Hufnagel (1992) highly confusable segment pairs) were used to familiarize the participants with the task. The responses from these stimuli were not included in the final analyses.

### Results

Participants were required to repeat each tongue twister six times. A repetition was scored as a speech error if a perseveration, anticipation, or exchange of the initial consonants was produced. Work by Shattuck-Hufnagel (1979; Shattuck-Hufnagel & Klatt, 1979) suggests that the first replacement in an exchange is the true cause of the exchange error; the second replacement occurs by default. Thus, to avoid inflating the error rate, individual phoneme errors were not counted and used in calculating the error rate. Rather, the entire repetition was scored as either correct or as an erroneous repetition if one or more errors occurred in that attempt to repeat the tongue twister.

Misreadings or insertions of segments that were not conditioned by the stimuli were not counted as speech errors because these errors presumably arise from sources other than the levels of representation under investigation. See Table 1 for examples of responses that were counted as errors and responses that, although not correct, were not counted as errors.

**Table 1.**

**Examples for the tongue twister "dash gab gaze doubt."**

<b>Responses counted as errors</b>	
<i>Examples</i>	<i>Reason response counted</i>
dash dab gaze doubt gash gab gaze doubt gash dab gaze doubt	perseveration anticipation exchange
<b>Responses not counted as errors</b>	
<i>Examples</i>	<i>Reason response not counted</i>
bash gab gaze doubt dash gab glaze doubt	misreading or unconditioned error

A one-way repeated measures ANOVA (dense vs. sparse neighborhood) was performed on the total number of erroneous repetitions for each condition of the 28 participants. A highly significant difference was observed ( $F_1(1, 27) = 16.88, p = .0003$ ;  $F_2(1, 18) = 6.16, p = .02$ ). More erroneous repetitions were found among tongue twisters containing words from sparse neighborhoods than among tongue twisters containing words from dense neighborhoods. The results are shown in Table 2.

**Table 2.**

**Mean number of erroneous repetitions  
(Standard deviations are in parenthesis)**

Number of Erroneous Repetitions	Neighborhood Density	
	<i>Sparse</i>	<i>Dense</i>
	7.5	4.2
	(5.4)	(3.0)

### Discussion

The results of the present speech error elicitation experiment found that more erroneous repetitions were produced among tongue twisters comprised of words with sparse neighborhoods than among tongue twisters comprised of words with dense neighborhoods. These results demonstrate that neighborhood density does affect the *accuracy* with which words are produced.

The present findings also replicate one of the results obtained from a corpus analysis by Vitevitch (1997b). Specifically, words with sparse neighborhoods are more prone to mis-productions than words with more dense neighborhoods. The current results extend the findings of Vitevitch (1997b) by demonstrating these effects with an experimental task which elicits speech errors rather than relying on corpora analyses. Furthermore, these results demonstrate that phonological similarity neighborhoods also influence speech production at other—sub-lexical—levels not just the word-form level, as the analysis of whole-word speech errors known as malapropisms suggests.

The present findings also have several implications for speech production and language processing in general. The influence of neighborhood density on phonological speech errors suggests that the activation of similar lexical items affects the processing of sublexical items. The influence of neighboring word-forms on sublexical representations may be easily accounted for by an interactive model of speech production (Dell, 1986, 1988, 1990; Harley, 1984). Dell (1986, 1988, 1990), for example, claims that activation spreads in a bi-directional manner between word-form representations and sub-lexical representations, thereby strengthening the activation of the desired word-form. It is unclear how the present results could be accounted for in serial-processing models of speech production (Garrett, 1980, 1988; Levelt et al., 1991).

Within an interactive activation framework similar to Dell's (1986, 1988, 1990), it is hypothesized that neighboring word-forms also activate sublexical representations. (Activation of neighboring word-forms may occur via activation spreading laterally from the intended word-form, or via activation spreading up from the sublexical level to all the word-forms that contain that sublexical representation.)

The activation that spreads from neighboring word-forms to sublexical items further strengthens the sublexical representations that comprise the intended word and, therefore, the intended word-form itself.

Intended word-forms in dense neighborhoods would presumably receive supportive activation from many neighboring word-forms, whereas intended word-forms in sparse neighborhoods would receive supportive activation from few neighboring word-forms via the sublexical level. Such a model would predict that intended word-forms that receive larger amounts of supportive activation (i.e., those in dense neighborhoods) would be less prone to phonological errors. Furthermore, intended word-forms that receive smaller amounts of supportive activation (i.e., those in sparse neighborhoods) would be more prone to phonological errors (see Taraban & McClelland, 1987, for a discussion of “gang effects”). How a serial-processing model of speech production (Garrett, 1980, 1988; Levelt et al., 1991) would account for the influence of neighborhood density on phonological speech errors is unclear.

The influence of variables such as word frequency, phonotactic information, and (as illustrated in the current study) neighborhood density on both speech production and speech perception raises some interesting questions about the processes and representations that are used in speech production and speech perception. Do speech production and speech perception access separate sets of representations? Alternatively, are there a common set of representations that are affected by the same lexical variables in different ways (depending on which “direction”—phonemes-to-concepts or concepts-to-phonemes—processing proceeds)? A related issue is whether models which have been proposed for only speech production or only speech perception can also account for the other process.

Although an early account of word recognition (Forster, 1978) also attempted to explain the production of words (and the mis-production of words), ensuing models proceeded to account for *either* perception (Luce & Pisoni, 1998; Marslen-Wilson and Welsh, 1978; McClelland & Elman, 1986; Norris, 1994) *or* production (Dell, 1986, 1988, 1990; Garrett, 1980, 1988; Harley, 1984; Levelt et al., 1991). In explicitly modeling only one process, researchers may have implicitly suggested that the representations and processes involved in speech production and speech perception may be separable.

A number of researchers, however, have suggested that production and perception are intimately interconnected (see, for example, Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; O’Seaghdha & Marin, 1997; Pisoni, Svirsky, Kirk, & Miyamoto, 1997). In light of this issue, it would be interesting to see if the neighborhood activation model (a model of spoken word recognition that was designed to account for neighborhood density effects in word recognition) can account for the current findings. The neighborhood activation model (NAM) proposes that similar sounding word-forms compete among each other in the word recognition process (Luce and Pisoni, 1998). If an incoming sound pattern activates many similar sounding items (i.e., a dense neighborhood) in the lexicon, word recognition will be slower and less accurate than for an incoming sound pattern which activates few similar sounding items (i.e., a sparse neighborhood) in the lexicon (Luce and Pisoni, 1998).

Because word frequency influences perception and production in an analogous manner (i.e., high frequency words are produced and recognized more quickly and more accurately than low frequency words), one might expect that neighborhood density affects production and perception analogously. That is, more speech errors should be found among words with dense neighborhoods. The results of the present experiment (see also Harley & Brown, in press; Vitevitch, 1997b) show that the opposite pattern is obtained in production; namely, more errors are found among words in sparse neighborhoods than dense neighborhoods.

The inability of NAM to account for the production findings could be due to a number of factors. One reason may be that NAM was designed as a model of word recognition not speech production. Despite many similarities between models of speech production and word recognition (e.g., in the representations they posit), it may be that no current model of word recognition can also account for speech production effects (and vice-versa). However, in light of the assumption that perception and production are interconnected (Lieberman et al., 1967; O'Seaghdha & Marin, 1997; Pisoni et al., 1997) such an explanation is unpalatable; a model of language processes should be able to account for both speech production and speech perception.

Alternatively, the current architecture of NAM may be insufficient to account for both speech production and speech perception data. The present instantiation of NAM consists of only a word-form level in which competition among similar sounding items occurs. Perhaps a sublexical level must be added to NAM in order for it to fully account for speech production as well as word recognition effects. Indeed, such a proposal was made recently by Vitevitch (1997b) in an effort to account for the results of the malapropism error corpus, as well as by Vitevitch (1997a) and Vitevitch and Luce (in press) in order to account for effects of phonotactics on spoken word recognition.

Although the present results do not directly address the broader issue of how language production and comprehension are interfaced, they do demonstrate that neighborhood density affects the accuracy with which words are produced. Specifically, words in dense neighborhoods tend to be produced more accurately than words in sparse neighborhoods. These findings are the opposite of neighborhood density effects in word recognition. (Recall that in word recognition, words in dense neighborhoods are recognized less accurately than words in sparse neighborhoods.) The findings from the present experiment contribute to a growing body of literature (Harley & Brown, in press; Vitevitch, 1997b) suggesting that lexical neighborhoods influence speech production in addition to speech perception. Neighborhood density effects in speech production pose a serious challenge to all contemporary accounts of speech production based on serial-processing models (e.g. Garrett, 1980, 1988; Levelt et al., 1991).

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## Appendix

<p style="text-align: center;"><b>LOW DENSITY TONGUE TWISTERS</b></p>	<p style="text-align: center;"><b>HIGH DENSITY TONGUE TWISTERS</b></p>
<p style="text-align: center;"> balm peach pig bull  rage weep wave rise  map noose noon mead  fig pawn pave fad  page case cave palm  leaf rice robe lung  birth gang gash bob  deem tame tide dose  save shell shun sour  dash gab gaze doubt </p>	<p style="text-align: center;"> wail reek reel weed  meal nail neat mole  fat pill pin fit  peep kit kin pick  lace road rock lag  gill beer bun goal  tuck den dial ton  pad bile bout par  shack seep sip shock  gore dame dill gull </p>