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### **SPEECH PERCEPTION: PHONOLOGICAL NEIGHBORHOOD EFFECTS ON WORD RECOGNITION PERSIST DESPITE SEMANTIC SENTENCE CONTEXT**

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Abstract:	<p>The present study tested the hypothesis that two lexical properties, both phonological neighborhood density (ND) and neighborhood frequency (NF), influence the recognition of target words whether preceded by either a semantically congruent or semantically neutral context, using, for the first time, a language other than English (i.e., Spanish) in this test. Target words were highly familiar bi-syllabic nouns with medium frequency occurrence. We expected recognition accuracy to increase as ND and NF decreased in both types of sentences. A set of 80 words (differing in ND and NF) were presented within semantically congruent or semantically neutral sentence contexts (i.e., 160 sentences) to 48 undergraduate listeners. We tested the relationships between ND, NF, and variations in semantic sentence context within a linear logistic model and found that words from sparse phonological neighborhoods (i.e., a low frequency of neighbors) were more likely to be correctly recognized in both sentence contexts indicating that overall, during word recognition, phonological competition outweighed the influence of semantic sentence context.</p>

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SPEECH PERCEPTION: PHONOLOGICAL NEIGHBORHOOD EFFECTS ON  
WORD RECOGNITION PERSIST DESPITE SEMANTIC SENTENCE CONTEXT

For Peer Review

Running head: Phonological Proximity and Sentence Context

## Abstract

The present study tested the hypothesis that two lexical properties, both phonological neighborhood density (ND) and neighborhood frequency (NF), influence the recognition of target words whether preceded by either a semantically congruent or semantically neutral context, using, for the first time, a language other than English (i.e., Spanish) in this test. Target words were highly familiar bi-syllabic nouns with medium frequency occurrence. We expected recognition accuracy to increase as ND and NF decreased in both types of sentences. A set of 80 words (differing in ND and NF) were presented within semantically congruent or semantically neutral sentence contexts (i.e., 160 sentences) to 48 undergraduate listeners. We tested the relationships between ND, NF, and variations in semantic sentence context within a linear logistic model and found that words from sparse phonological neighborhoods (i.e., a low frequency of neighbors) were more likely to be correctly recognized in both sentence contexts indicating that overall, during word recognition, phonological competition outweighed the influence of semantic sentence context.

Keywords: auditory word recognition, phonological proximity, sentence context.

## Introduction

It has been well established that the number of similar-sounding words in a mental lexicon is an important factor influencing word recognition in speech perception. Recognition of a spoken word requires the listener to match the acoustical input corresponding to the speech signal with the correct lexical entry in the mental lexicon. The acoustical information corresponding to a given word is quite variable due to different speaking characteristics (speaking accent, speech rate, dialect, etc.) and environmental listening conditions such as background noise, reverberation, etc. Therefore, it is unlikely that the acoustical information corresponding to the speech signal would be sufficient to activate a single word's entry into the mental lexicon consisting of thousands of words stored in long-term memory (Luce & Pisoni, 1998; Vitevitch & Luce, 2016). Most models of spoken word recognition assume that word recognition involves the activation of similar-sounding words in the mental lexicon, but there are some differences among the models regarding the details of this process. The TRACE model (McClelland, & Elman 1986), Shortlist (Norris & McQueen 2008) and PARSYN (Luce, Goldinger, Auer, & Vitevich, 2000) are all interactive, localist connectionist models, that have various processing units such as features, phonemes and words, with excitatory and inhibitory connections that raise or lower the perceiver's activation of word candidates in the recognition process. The Dynamic Causal Modeling (DCM) (Gaskell & Marslen-Wilson, 1997) is also an interactive model, but unlike TRACE, Shortlist, and PARSYN, in DCM, information is distributed so that intermediate levels of representation are not needed. Nonetheless, all of these models postulate that phonological competition is a function of the similarity of competing words to the auditory input. These sets of similar sounding words compete for recognition. One of the most well-known phonological competition sets is the

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3 phonological “neighborhood,” defined as a set of words that can be formed by deleting,  
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5 adding or substituting a single phoneme (Luce & Pisoni, 1998).  
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8           The Neighborhood Activation Model (NAM) (Luce & Pisoni, 1998)  
9  
10 provides a theoretical framework for explaining how the lexical neighborhood  
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12 influences spoken word recognition. This model examines not only the effects of  
13  
14 similar sounding words, but also their frequency of occurrence. According to  
15  
16 NAM, words with a small number of similar sounding neighbors or  
17  
18 “neighborhood density “(ND) are recognized faster and more accurately than  
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20 words with a high number of neighbors. Similarly, independent of the number of  
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22 neighbors, when the frequency of neighbors (“neighborhood frequency” [NF]) is  
23  
24 low, words are more easily recognized. Thus, words with both high numbers of  
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26 neighbors (ND) and high frequency of their occurrence (NF) are “hard” words  
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28 that are more difficult to recognize than words with low ND and low NF, “easy”  
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30 words. These effects have been demonstrated in several studies using a variety of  
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32 experimental tasks, such as the perceptual identification task (Goldinger, Luce &  
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34 Pisoni, 1989; Luce & Pisoni, 1998; Sommers & Danielson, 1999; Taler, Aaron,  
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36 Steinmezt, & Pisoni, 2010), auditory lexical decision task (Luce & Pisoni, 1998;  
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38 Vitevich & Luce, 1999), naming task (Luce & Pisoni, 1998; Vitevith & Luce,  
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40 1998, 1999), and “slips of the ear” task involving naturally occurring perceptual  
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42 errors where it is common for listeners to misperceive a word the speaker  
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44 pronounces correctly (Vitevich, 2002). These studies showed that the effects of  
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46 ND and NF on spoken word recognition depended on the experimental task and  
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48 the language spoken. For instance, in the Spanish language, high ND has been  
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50 found to facilitate lexical decision tasks, while, in English, high ND inhibits  
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52 lexical decision making (Vitevitch & Rodriguez, 2005). In addition, using a  
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3 perceptual identification task, the effects of high ND were inhibitory in French  
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5 (Dufour & Fraunfeldner, 2007) and Japanese (Amano & Kondo, 2000), as first  
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7 observed in English by Luce and Pisoni (1998).  
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10           Although the influence of the phonological neighborhood on word  
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12 recognition when words are presented out of context has been investigated with  
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14 various tasks and in various languages, the influence of phonological  
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16 neighborhood on word recognition when words are embedded in varied sentence  
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18 contexts has rarely been studied, and so it is poorly understood. On the one hand,  
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20 Marslen-Wilson and Tyler (1980) demonstrated that a constraining linguistic  
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22 context produced a dramatic reduction in the number of possible word candidates  
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24 that share the same initial sounds as the target word (the “cohort”), while, on the  
25  
26 other hand, Zwitselood (1989) presented a semantically constrained sentence with  
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28 a final target word followed by either a prime word related to the target word or a  
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30 neighbor of that word and found some word recognition facilitation for both  
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32 conditions.  
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38           The small number of studies that have investigated the role of ND and NF  
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40 in word recognition within varied sentence contexts (Sommers & Danielson,  
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42 1999; Taler, et al., 2010) found that the semantic sentence context did not totally  
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44 eliminate the influence of ND and NF. In these studies, the ND and NF inhibitory  
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46 effects persisted, although these effects were lower in semantically congruent  
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48 versus semantically neutral or less predictable sentence contexts. These results are  
49  
50 more consistent with interactive models of language processing than with  
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52 modular models **that** postulate a discrete separation of different levels of language  
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54 representations and processing (Forster, 1978) **and** would predict that when the  
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56 individual listens to a word preceded by semantic linguistic information,  
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3 phonological neighbors are inevitably activated, regardless of the presence of a  
4 meaningful sentence context, because the flow of information across the different  
5 processing stages is ordered bottom-up from lower to higher stages. But,  
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8 interactive models (TRACE, Shortlist, DCM, NAM) assume that information  
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10 flows in both directions, from lower to higher levels and top-down; and thus,  
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12 these models would postulate that context restricts lexical alternatives in the  
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15 earliest stages (e.g., Brock & Nation, 2013).  
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19 The studies by Sommers and Danielson (1999) and Taler, Aaron,  
20 Steinmezt, and Pisoni (2010) employed an **experimental** task of identifying a  
21 target word within a sentence, using English speech stimuli. To our knowledge,  
22  
23 there have been no studies in other languages. While it is clear that a meaningful  
24 sentence context facilitates word recognition, and these beneficial effects were  
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26 shown quite early using sentences in a noisy environment (e.g. Kalikow, Stevens,  
27 & Elliot, 1977) the question of whether the phonological neighborhood plays a  
28 significant role in word recognition when a target word is heard in a meaningful  
29 sentence context versus in an out-of-context sentence has not been explored in  
30 Spanish. This is the objective of the present study, and its practical applications  
31 include the provision of guidance to researchers and clinicians in developing  
32 stimuli for evaluating speech perception in individuals with auditory or cognitive  
33 deficits for whom it is important to attend to both acoustical and phonetic  
34 characteristics and any other important lexical properties or semantic information  
35 conveyed by the sentence heard. Based on findings from Sommers and Danielson  
36 (1999) and Taler et al., (2010), we expected that: (a) word recognition accuracy  
37 would be higher in congruent than in neutral sentence contexts; (b) recognition  
38 accuracy would increase as ND and NF decrease, and that ND and NF  
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3 characteristics would interact, producing the classical difference between easy  
4 and hard-to-recognize words; and (c) there would be ND and NF effects in both  
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6 congruent and neutral sentence contexts.  
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## 10 11 12 **Method**

### 13 14 **Participants**

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16 Participants in this experiment were 48 undergraduate students, 31 female, and  
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18 17 male, aged 22-28 years ( $M = 23.7$ ,  $SD = 2.6$  years). These students participated  
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20 voluntarily and received partial credit for a course requirement. No participants reported  
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22 having any hearing or language problems, and all were native speakers of Castilian  
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24 Spanish. The research conformed to the American Psychological Association's Ethical  
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26 Principles of Psychologists and Code of Conduct (APA, 2002, as amended in 2010). All  
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28 participants signed informed consent forms.  
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### 34 35 **Materials**

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37 As described above, speech stimuli in the present experiment were 160  
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39 spoken sentences extracted from the [Spanish Sentence Lists \(SSL\)](#) (Cervera &  
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41 González, 2010). Half of the sentences had a final target word that was  
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43 predictable from the preceding sentence context (congruent sentences) (e.g.,  
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45 "Para leer necesito gafas," [I have to put my glasses on to read]). The final target  
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47 word in the other half of the sentences could not be predicted by the preceding  
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49 words (neutral sentences) (e.g., "Ella estaba hablando sobre gafas," [She was  
50  
51 talking about glasses]). Each congruent sentence had a corresponding neutral  
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53 sentence, so that the same final word appeared in both types of sentences. The  
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55 predictability of the target word in the congruent sentences was determined by the  
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3 cloze procedure, in which the final word sentence in the was omitted and the  
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5 listeners were required to fill in the blank, ranging from 45%-75%; thus, avoiding  
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7 very low or high probabilities.  
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10 The target words were similar with regard to frequency of occurrence,  
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12 familiarity, contextual diversity, duration (2000 ms), and syllabic-stress with  
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14 emphasis on the first syllable. In addition, all the words were nouns (avoiding  
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16 verbs because of their rich morphology in Spanish) and had two syllables. Word  
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18 morphology and length influence word recognition and seem to explain some of  
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20 the differences between the results obtained when using English versus Spanish  
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22 speech stimuli (Vitevith & Rodriguez, 2005; Vitevitch & Stammer, 2009).  
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24 Additionally, the words differed in ND and NF.  
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28 The lexical characteristics of these words were obtained from  
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30 the EsPAL database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013).  
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32 The target words were mid-frequency but highly familiar words. Words with  
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34 more than 20 neighbors were considered high ND words, whereas words with  
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36 fewer neighbors were considered low ND words. Likewise, words whose  
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38 neighbors had a mean frequency greater than nine occurrences per million were  
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40 considered high NF, and words below this value were considered low NF words.  
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42 In both cases, we used the median number to divide words into ND and NF  
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44 groups (Table 1). The target words are presented in Appendix I.  
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## 51 **Instruments**

52 All the sentences were digitally recorded (using a 16-bit A/D converter)  
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54 by a native Castilian-Spanish speaking female in a sound-proof room with a  
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56 Sennheiser HMD 224 microphone at a sampling frequency of 20 kHz, and 8.5  
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3 kHz low-pass filtering. The duration of the utterance was between 1800 to 2000  
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5 ms, and each sentence was equated on the root mean square (RMS) across the  
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7 entire sentence and stored in different digital files. Babble noise (at 10 dB signal-  
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9 to noise-ratio, SNR) was added to the speech signal to avoid ceiling effects on the  
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11 scores of the perceptual identification task. Previous data suggested that the  
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13 lexical neighborhood emerges in the auditory domain when the speech signal is  
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15 degraded (e.g. Goldinger, Luce, & Pisoni, 1989). The babble noise was generated  
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17 by mixing 12 voices six males and six females. The +10dB SNR condition was  
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19 created by manipulating the overall RMS of both the signal and the noise. These  
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21 manipulations were performed using Adobe Audition Pro software.  
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## 28 **Procedure**

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30 We used the perceptual identification task because it seems to be the most  
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32 consistent task cross-linguistically in studies of neighborhood effects of isolated  
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34 word recognition, and because it was used in past studies by Sommers and  
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36 Danielson (1999) and Taler et al. (2010). The perceptual identification task took  
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38 place in a sound attenuated room. The listeners were presented with the stimuli  
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40 through Sennheiser headphones connected to a Pentium PC. A computer program  
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42 especially designed for this task administered and registered the listeners'  
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44 responses. The listeners were instructed to listen to each sentence and type the last  
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46 word of the sentence they heard using the computer keyboard, and then press the  
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48 space bar. After two seconds the next stimulus was presented. Prior to the  
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50 experiment, we presented eight different practice sentences. Each listener was  
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52 presented with half of the words in a congruent sentence and the other half in  
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54 neutral sentence conditions, so that the listener did not hear the same word twice.  
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3 The ND and NF characteristics of word presentation were counterbalanced in  
4 each condition. The 48 participants were randomly assigned to either the  
5 congruent sentence or neutral sentence condition, and the order of stimuli  
6 presentation within each condition was random.  
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## 12 Results

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14 Recognition accuracy was measured as the number of target words correctly  
15 identified later, converted to percentages. For descriptive purposes, the mean  
16 recognition percentages in each experimental condition are presented in Table 2. The  
17 dependent variable was the binary value of correct versus incorrect word recognition  
18 accuracy for each word by each individual participant; and analyses were by mixed-  
19 effects binary logistic regression. Participants and items were random effects, whereas  
20 Context (congruent or neutral sentences), ND (high or low), and NF (high or low) were  
21 fixed effects. In addition,  $Exp(B)$  (the exponentiation B coefficients) values had an odds  
22 ratio interpretation and could be used to assess the predicted magnitude of the effects of  
23 each independent variable. The statistical analyses were performed using the SPSS  
24 software package.  
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41 An omnibus test of model coefficients was significant ( $\chi^2 = 428.55, p < .001$ ).  
42 The three fixed effects (Context, ND, and NF) were significant. A significant fixed  
43 effect of Context was obtained; as expected, participants provided significantly more  
44 correct responses in semantically congruent sentences than in neutral sentences (Wald  $Z$   
45 = 33.88,  $p < .001$ ,  $Exp(B) = 3.41$ ). Likewise we found significant effects for ND (Wald  
46  $Z = 36.07, p < .05$ ,  $Exp(B) = 0.41$ ) and NF (Wald  $Z = 34.58, p < .001$ ,  $Exp(B) = 0.42$ );  
47 and, as expected, correct responses were greater for low ND words than for high ND  
48 words, and for low NF words than for high NF words. From the  $Exp(B)$  values, it can be  
49 observed that the magnitude of the effect was greater for Context than for the ND and  
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3 NF variables. Regarding the interactions, the Context x NF interaction was significant  
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5 (Wald  $Z = 13.27$ ,  $p < .001$ ,  $Exp(B) = 2.97$ ), indicating that the recognition was higher  
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7 for low NF than for high NF in the neutral-sentence condition, but not in the congruent-  
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9 sentence condition. However, the Context X ND interaction was not significant (Wald  $Z$   
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11  $= 3.27$ ,  $p = 0.07$ ,  $Exp(B) = 0.63$ ). The ND x NF interaction was significant (Wald  $Z =$   
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13  $13.18$ ,  $p < .001$ ,  $Exp(B) = 2.04$ ), indicating that the effects of ND differed, depending  
14  
15 on whether NF was high or low. In other words, as expected, low ND and low NF  
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17 words (easy words) were identified more accurately than were high ND and high NF  
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19 words (hard words). The most interesting result was the absence of a significant Context  
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21 x ND x NF interaction (Wald  $Z = 0.31$ ,  $p = 0.58$ ,  $Exp(B) = 0.81$ ) indicating that the  
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23 effects of lexical characteristics (ND and NF) on word recognition were evident in both  
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25 congruent and neutral sentence contexts.  
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33 Insert Table 2 about here  
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## 40 Discussion

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42 The objective of the present study was to assess lexical neighborhood effects  
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44 (ND and NF) on the recognition of spoken words embedded in varied sentence contexts.  
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46 Although the lexical neighborhood has had well-known factor effects on phonological  
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48 categorization in word recognition in past research, its effects on word recognition when  
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50 target words are presented within a sentence (rather than individually) and preceded by  
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52 semantically meaningful or neutral information have been studied less.  
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57 Our results showed that not only sentence context but also lexical phonological  
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59 properties, ND and NF, affected word recognition. As expected, a semantically  
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3 congruent sentence context increased target word recognition compared to a  
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5 semantically neutral context. As in previous studies using English sentences (Sommers  
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7 & Danielson, 1999; Taler et al., 2010), our results showed inhibitory effects of the  
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9 lexical neighborhood on target word recognition, even in semantically constrained  
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11 sentences. In other words, when participants listened to an acoustic signal  
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13 corresponding to a word (a signal that was not sufficient for a single lexical hypothesis  
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15 due to some deterioration from background noise) a congruent sentence context biased a  
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17 given meaning, but it did not keep a number of similar sounding words from being  
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19 activated in memory competing for recognition and producing inhibitory word  
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21 recognition effects.  
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26 Our prediction of an interactive influence of ND and NF on word identification  
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28 was confirmed in both the meaningful and neutral sentence contexts. Similar to the  
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30 results of prior studies using isolated words as stimuli (Luce & Pisoni, 1998), not only  
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32 the number of phonological neighbors, but also their frequency of occurrence,  
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34 influenced word recognition. In both meaningful and neutral sentence contexts  
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36 predicted word recognition differences between words that were easy and hard in their  
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38 phonological characteristics were evident. This difference tended to be greater (but not  
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40 statistically significant) for the neutral sentence condition (21% recognition difference  
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42 of easy versus hard words) than for the semantically congruent sentence condition (5%  
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44 recognition difference for easy versus hard words). In the neutral sentence condition,  
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46 hard words were correctly perceived with 58% frequency and easy words were  
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48 perceived with 79% frequency. In congruent sentences, hard words were recognized  
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50 with 88% frequency and easy words were recognized with 93% frequency. These  
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52 results are consistent with those from Sommers and Danielson (1999), who compared  
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54 easy and hard words in isolation and in a preceding sentence context. These results also  
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3 coincide with Taler et al. (2010), who used sentences consisting of three target words  
4 that differed in ND and NF and in meaningful or neutral sentence contexts, as in the  
5 present study. In general, we showed inhibitory effects of the lexical neighborhood on  
6 word recognition performance, in spite of a semantically biasing sentence context.  
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8 Thus, semantic context seems insufficient to restrict lexical competition.  
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14           It should be noted that that these results were obtained with one particular task  
15 (word identification), two types of sentences, and specific target words (nouns,  
16 disyllabic, mid-frequency), restricting the generalization of these findings to other  
17 experimental tasks, types of sentences, and target words. For instance, the congruent  
18 sentences used in the present study were quite predictable, but they did not constrain  
19 responses to a unique word candidate. Our semantically neutral sentences were not  
20 semantically inappropriate or implausible. In addition, the present study controlled the  
21 target words for length and morphology, addressing suggestions that these two lexical  
22 characteristics explained some of the differences between Spanish and English in prior  
23 studies with isolated words. Thus, the limitation of the present study is that the  
24 conclusions are restricted to words with the characteristics employed in the present  
25 study. Future researchers should consider different types of target words and  
26 experimental tasks.  
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Table 1. Lexical properties of the target words and significant group differences.

	High ND-high NF Mean (SD)	high ND-low NF Mean (SD)	low ND-high NF Mean (SD)	low ND-low NF Mean (SD)	F(df)	p
log frequency	1.37 (0.31)	1.94 (0,27)	1.46 (0,37)	1.45(0.23)	0.29(3)	ns
Contextual diversity	12372 (11012)	11651 (12020)	12594 (13683)	10591 (8334)	0.11(3)	ns
Familiarity	6 (0,37)	6 (2)	6 (1)	6 (0,3)	0.13(3)	ns
ND	40 (11)	31 (9)	14 (7)	11 (4)	50.56 (3)	<.01
NF	40 (28)	5 (3)	24 (19)	5(3)	20.81 (3)	<.01

Note: ND = neighborhood density (number of neighbors), NF = neighborhood frequency (mean average frequency of the neighbors), ns = no significant.

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Table 2. Mean (and SD) of recognition accuracy (number of words correctly identified expressed as percentage) in each experimental condition.

		Mean (SD)	Mean (SD)
		High NF	Low NF
Congruent sentences	High ND	88 (33)	78 (42)
	Low ND	94 (23)	93 (20)
		High NF	Low NF
Neutral sentences	High ND	58 (49)	62 (48)
	Low ND	61 (49)	79 (40)

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## Appendix I. List of target words.

high ND - high NF	high ND - low NF	low ND - high NF	low ND - low NF
salto (jump)	torre (tower)	cinta (ribbon)	blusa (blouse)
arte (arts)	caos (chaos)	baile (dance)	premio (award)
bata (coat)	banda (band)	banco (bank)	polvo (dust)
barro (mud)	pila (pile)	firma (signature)	cauce (riverbed)
aves (birds)	arco (arc)	pausa (pause)	brisa (breeze)
caza (hunting)	taza (cup)	uñas (nails)	ciclo (cycle)
cera (wax)	raza (race)	norma (rule)	clima (weather)
sopa (soup)	cima (top)	tinta (ink)	danza (dance)
guía (guide)	burro (donkey)	pista (path)	metro (subway)
lago (lake)	cita (date)	novio (groom)	gafas (glasses)
rama (branch)	hielo (ice)	verso (verse)	lujo (luxury)
raya (stripe)	gala (gala)	dueña (owner)	noble (noble)
trago (sip)	alba (sunrise)	presa (prey)	gozo (joy)
polo (icecream)	plaza (square)	ríos (rivers)	taxi (taxi)
muro (wall)	gases (gases)	nuca (nape)	selva (jungle)
pase (pass)	gallo (rooster)	tienda (shop)	regla (rule)
beso (kiss)	cura (priest)	dardo (dart)	hueso (bone)
ducha (shower)	tela (cloth)	vena (vein)	joyas (jewelry)
seda (silk)	fila (row)	chino (chinese)	nubes (clouds)
misa (mass)	males (harm)	letra (letter)	mueca (grin)

Note. ND = neighborhood density, NF = neighborhood frequency