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Neighborhood density effects in spoken word recognition in Spanish

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Abstract
The present work examined the relationships among familiarity ratings, frequency of occurrence, neighborhood density, and word length in a corpus of Spanish words. The observed relationships were similar to the relationships found among the same variables in English. An auditory lexical decision task was then performed to examine the influence of word frequency, neighborhood density, and neighborhood frequency on spoken word recognition in Spanish. In contrast to the competitive effect of phonological neighborhoods typically observed in English, a facilitative effect of neighborhood density and neighborhood frequency was found in Spanish. Implications for models of spoken word recognition and language disorders are discussed.

Keywords: *Word recognition, Spanish*

Given the various differences that exist across the languages of the world, it is important to determine if the *same factors* affect processing *in the same way* in all languages. Computational analyses of lexical databases (e.g., Zipf, 1935; Landauer, & Streeter, 1973; Pisoni, Nusbaum, Luce, & Slowiacek, 1985; see also Bard, & Shillcock, 1993; Cutler, & Carter, 1987) can be used in conjunction with data from behavioral experiments to determine if factors such as familiarity, frequency of occurrence, neighborhood density,[1] and word length influence all languages in the same way, thereby better constraining theories of word recognition. The present analysis examined these lexical characteristics in a small subset of words ($n = 1584$) selected from a Spanish database that contained over 175 000 word types (Sebastián Gallés, Martí-Antonín, Carreiras-Valiña, & Cuetos Vega, 2000).[2] The present analysis is similar to analyses that have examined English, Dutch (Frauenfelder, Baayen, Hellwig, & Schreuder, 1993), and Japanese (Yoneyama, & Johnson, 2001). In the present analysis a neighbor was defined as a lexical item that was formed by the substitution of a letter into the target word (cf., Landauer, & Streeter, 1973; Luce, & Pisoni, 1998). Word length was measured by the number of letters and the number of syllables in the word. Summary data for the variables that were examined are provided in Table I.

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Table I. Summary data for the words obtained from a Spanish lexicon.

Number of syllables	Number of letters	Percentage of words	Familiarity	Frequency	Number of neighbors
1	3.1 (0.5)	2.8	5.3 (1.2)	620.2 (937.3)	13.4 (6.7)
2	4.7 (0.7)	59.4	5.3 (1.2)	240.1 (484.9)	9.1 (6.0)
3	6.5 (0.8)	30.8	5.1 (1.2)	149.2 (246.8)	3.9 (1.9)
4	8.5 (0.9)	5.9	5.1 (0.9)	119.1 (217.1)	2.7 (1.0)
5	10.2 (1.0)	< 1	5.4 (0.8)	89.3 (89.7)	2.4 (0.5)
6	12.0 (0.0)	< 1	4.9 (1.4)	293.5 (355.6)	2.5 (0.7)

Note: Standard deviations are in parenthesis. Because Spanish has a shallow orthography (i.e., there is close to a one-to-one correspondence between orthography and phonology) the number of letters and phonemes in a word will be very similar in Spanish.

Correlation coefficients (all $n = 1584$) and significance values (using a Z-test) for the correlations were calculated for the relationships of interest. All reported effects were significant at $p < 0.01$, unless noted otherwise. A significant negative correlation was found between frequency of occurrence and word length, such that words that occur in the language more often tended to be shorter than words that occur in the language less often (word length-syllables, $r = (0.15$; word length-letters, $r = (0.14)$. This result replicates the findings of Zipf (1935) who found a similar relationship between word length and frequency of occurrence in English, Latin, and Chinese (Zipf also reported data by F. W. Kaeding, who described this relationship in German as well). Word length also correlated negatively with the number of neighbors: short words had many neighbors, whereas longer words had fewer neighbors. This relationship was significant whether word length was measured in number of syllables ($r = (0.47$) or number of letters ($r = (0.61$). Pisoni et al. (1985) observed a similar relationship between word length and neighborhood density in English.

Landauer and Streeter (1973) observed that compared to rare words, common words had more neighbors in English (cf., Pisoni et al., 1985; Frauenfelder et al., 1993). An examination of the Spanish data shows a similar relationship. Frequency of occurrence was significantly and positively correlated with neighborhood density: frequency and number of neighbors, $r = 0.09$. In Spanish, like in English, words that occur often in the language tended to be similar to many words, whereas words that occur less often are similar to fewer words. The frequency with which a word occurred in Spanish was also positively correlated with the subjective familiarity rating of that word ($r = 0.28$), replicating previous studies in English (cf., Begg, & Rowe, 1972; Gernsbacher, 1984; Kreuz, 1987).

The results of the present analyses showed that the relationships among familiarity, word frequency, neighborhood density, and word length found in other languages (e.g., Frauenfelder et al., 1993; Yoneyama, & Johnson, 2001) are also found in Spanish. Finding the same relationships among these variables is somewhat surprising, given a difference in typical word length between English and Spanish. For example, Perea, Gotor, and Miralles (1988) found that words in Spanish were significantly longer than words in English when the number of phonemes in a word was used to measure word-length. A similar result is found in our analysis: two and three syllable words accounted for 90% of the tokens in Spanish, whereas Zipf (1935) found that one to two syllable long words account for approximately 80% of the tokens in English. The difference in word-length between the two languages is interesting because word length has also been shown to influence spoken word recognition. Examining only English words, Wiener and Miller (1946) found that longer words were identified more accurately than shorter words. If words in a given language, like Spanish, are typically longer—and perhaps more easily recognized—than words in another language, like English, then different processes may be used to recognize spoken words in the two languages. The following auditory lexical decision task was conducted to examine how the difference in typical word length between Spanish and English might influence spoken word recognition.

Experiment

In an auditory lexical decision task a word or a nonsense word is presented over a set of headphones, and listeners must decide as quickly and as accurately as possible whether the stimulus they heard was a real word or a made-up nonsense word. The words in this experiment varied in word frequency, neighborhood density, and neighborhood frequency. Recall, word frequency refers to how often a word occurs in the language, and neighborhood density refers to the number of neighbors a word has. A word with few phonologically similar words is said to have a sparse neighborhood, whereas a word with many phonologically similar words is said to have a dense neighborhood. *Neighborhood frequency* refers to the mean frequency of the neighbors (Luce, & Pisoni, 1998); note, this variable was not available in the Sebastian-Galles et al. (2000) database, and was therefore not examined in the analysis of the lexical database. The words used in this experiment consisted of a subset of words from a study by Alameda and Cuetos (1996) that examined the effects of neighborhood density in visual word recognition. Although others have examined the influence of neighborhood density in visual word recognition in Spanish (e.g., Carreiras et al., 1997), the present experiment is—to the best of our knowledge— the first to examine the influence of neighborhood density on *spoken* word recognition in Spanish.

Previous studies of spoken word recognition in English have found that—across a variety of tasks and listener populations—words with sparse phonological neighborhoods are recognized more quickly and accurately than words with dense neighborhoods (e.g., Sommers, 1996; Kirk, Pisoni, & Miyamoto, 1997; Luce, & Pisoni, 1998; Vitevitch, & Luce, 1998, 1999; Vitevitch, 2002b; see also Vitevitch, 2002a, for neighborhood density effects in word onset). Furthermore, all current models of spoken word recognition propose some mechanism to account for competition among similar sounding word forms (e.g., McClelland, & Elman, 1986; Luce, & Pisoni, 1998; Norris, McQueen, & Cutler, 2000). Therefore, we predicted a competitive influence of neighborhood density in the present auditory lexical decision task. We further predicted that words with high frequency of occurrence would be responded to more quickly and accurately than words with low frequency of occurrence, and that words with low frequency neighborhoods should be responded to more quickly and accurately than words with high frequency neighborhoods. However, given the findings of Wiener and Miller (1946) regarding the influence of word length on spoken word recognition, and the difference in typical word length between English and Spanish, a very different pattern of results might be observed. The following auditory lexical decision task was conducted to examine how the difference in typical word length between Spanish and English might also influence the process of spoken word recognition.

Method

Participants

Thirty-eight adult native Spanish-speakers were recruited from the University of Kansas community. Sixteen participants were male, and 22 participants were female. All of the participants were born in a country in which Spanish was the dominant language, received most, if not all, of their undergraduate education at institutions in which Spanish was the language of instruction, and came to the University of Kansas for graduate education (mean age = 27.16 years). None of the participants reported a history of speech or hearing disorders, all were right-handed, and all received $10 for their participation. Note that all communication with the participants (e.g., recruitment flyers, consent forms, instructions, etc.) was conducted in Spanish by the second author, a native speaker of Spanish. A technical problem resulted in the loss of data from one participant.

Materials

The stimuli consisted of 80 bisyllabic Spanish nouns and 80 bisyllabic nonwords containing four letters. Changing the letter in the last position of each word formed the nonwords; consonants were replaced by consonants, and vowels were replaced by vowels. The stress pattern of the nonwords was the same as the stress pattern of the words from which they were derived. For example, the nonword *niñi* was formed from the stimulus word *niña* (*child*), and the nonword *olop* was formed from the stimulus word *olor* (*odor*). The last letter was changed to maintain wordlikeness in the beginning of the stimulus, thereby decreasing the likelihood that listeners would listen just to the first part of each stimulus item before making a decision about it. The nonwords were also nonwords in English. Eight conditions, each containing ten words, were formed by orthogonally combining two levels of word frequency (high and low), neighborhood density (sparse and dense), and neighborhood frequency (high and low).

The log value for high-frequency words (mean = 2.3; based on the values in Alameda, & Cuetos, 1996) was significantly higher than the log value for low-frequency words (mean = 1.5; $F(1,72) = 198.02$, $p < 0.001$). Despite the difference in word frequency, all of the words were relatively common in the language. Words with sparse neighborhoods had significantly fewer neighbors (mean = 6.9 words), than the words with dense neighborhoods (mean = 15.0 words; $F(1,72) = 152.88$, $p < 0.001$). The words with high neighborhood frequency (mean = 2.2) had neighbors with significantly higher log frequency values of word frequency than the neighbors of words with low neighborhood frequency (mean = 1.6; $F(1,72) = 141.71$, $p < 0.001$).

All of the stimuli were spoken in isolation and recorded by the second author in an IAC sound attenuated booth using a high-quality microphone on digital audio tape at a sampling rate of 44.1 kHz. The digital recordings were then transferred directly to hard-drive via an AudioMedia III card and Pro Tools LE software (both made by Digidesign), and edited into individual digital files (16 bit) that were stored on computer disk for later playback. Duration values of the nonwords and all eight conditions of the real words were equivalent ($F(8,151) < 1$).

Procedure

Participants were tested in groups of three or less. Each participant was seated in a booth equipped with an iMac running PsyScope 1.2.2 (Cohen, MacWhinney, Flatt, & Provost, 1992) that controlled stimulus randomization and presentation. Response latencies were collected with millisecond accuracy via a New Micros button box interfaced to the computer. A trial proceeded as follows: a string of asterisks appeared in the center of the computer screen for 500 ms to indicate the beginning of a trial. The asterisks were removed and one of the randomly selected stimuli was presented over a pair of Beyerdynamic DT-

100 headphones. Reaction times were measured from the onset of the stimulus to the onset of the button press response. Participants were instructed to respond as quickly and as accurately as possible. If the item was a word, they were to press the button labeled Sí (yes). If the item was not a word (i.e., it was a nonword), they were to press the button labeled No (no). Note that the "yes" response was made with the dominant hand of each participant. Prior to the experimental trials, each participant received ten practice trials. These trials were used to familiarize the participants with the task and were not included in the final analysis.

Results

Repeated-measures analysis of variance was used for each dependent measure (reaction time and accuracy rates). Unless indicated otherwise, all reported analyses were significant at $p < 0.01$. For the reaction times, a main effect of word frequency was found ($F(1,36) = 42.48$): high frequency words (mean = 932 ms) were responded to more quickly than low frequency words (mean = 979 ms), replicating previous studies of the influence of word frequency on spoken word recognition. A main effect of neighborhood density was found ($F(1,36) = 9.85$): words with dense neighborhoods (mean = 945 ms) were responded to more quickly than words with sparse neighborhoods (mean = 966 ms). This result is the opposite of what is observed in English (e.g., Luce, & Pisoni, 1998). A main effect of neighborhood frequency was found ($F(1,36) = 12.77$): words with high frequency neighborhoods (mean = 942 ms) were responded to more quickly than words with low frequency neighborhoods (mean = 968 ms). Like the result for neighborhood density, this result is the opposite of what is observed in English (e.g., Luce, & Pisoni, 1998).

A two-way interaction between word and neighborhood frequency was also significant ($F(1,36) = 10.31$). Among low frequency words, there was no difference between words with high neighborhood frequency (mean = 977 ms) and words with low neighborhood frequency (mean = 980 ms). However, high frequency words with high neighborhood frequency (mean = 907 ms) were responded to more quickly than high frequency words with low neighborhood frequency (mean = 956 ms; $F(1,36) = 23.31$). None of the other two-way interactions were significant.

The main effects and the two-way interaction must be considered in the context of a significant three-way interaction ($F(1,36) = 10.30$), shown in Figure 1. This interaction was due to the response pattern found among low frequency words with dense neighborhoods. Pair-wise comparisons showed that low frequency words with dense, high frequency neighborhoods (mean = 981 ms) were responded to more slowly than low frequency words with dense, low frequency neighborhoods (mean = 957 ms; $F(1,36) = 5.15$, $p < 0.05$). This pattern is the opposite of the other conditions displayed in Figure 1. Pair-wise comparisons also showed that each of these other conditions were significantly different and in the opposite direction: low frequency words with sparse, high frequency neighborhoods (mean = 974 ms) were responded to more quickly than low frequency words with sparse, low frequency neighborhoods (mean = 1003 ms; $F(1,36) = 7.99$); high frequency words with dense, high frequency neighborhoods (mean = 893 ms) were responded to more quickly than high frequency words with dense, low frequency neighborhoods (mean = 949 ms; $F(1,36) = 28.90$); high frequency words with sparse, high frequency neighborhoods (mean = 922 ms) were responded to more quickly than high frequency words with sparse, low frequency neighborhoods (mean = 964 ms; $F(1,36) = 16.43$).

For the accuracy rates (also displayed in Figure 1), a main effect of word frequency was found ($F(1,36) = 34.20$): high frequency words (mean = 94%) were responded to more

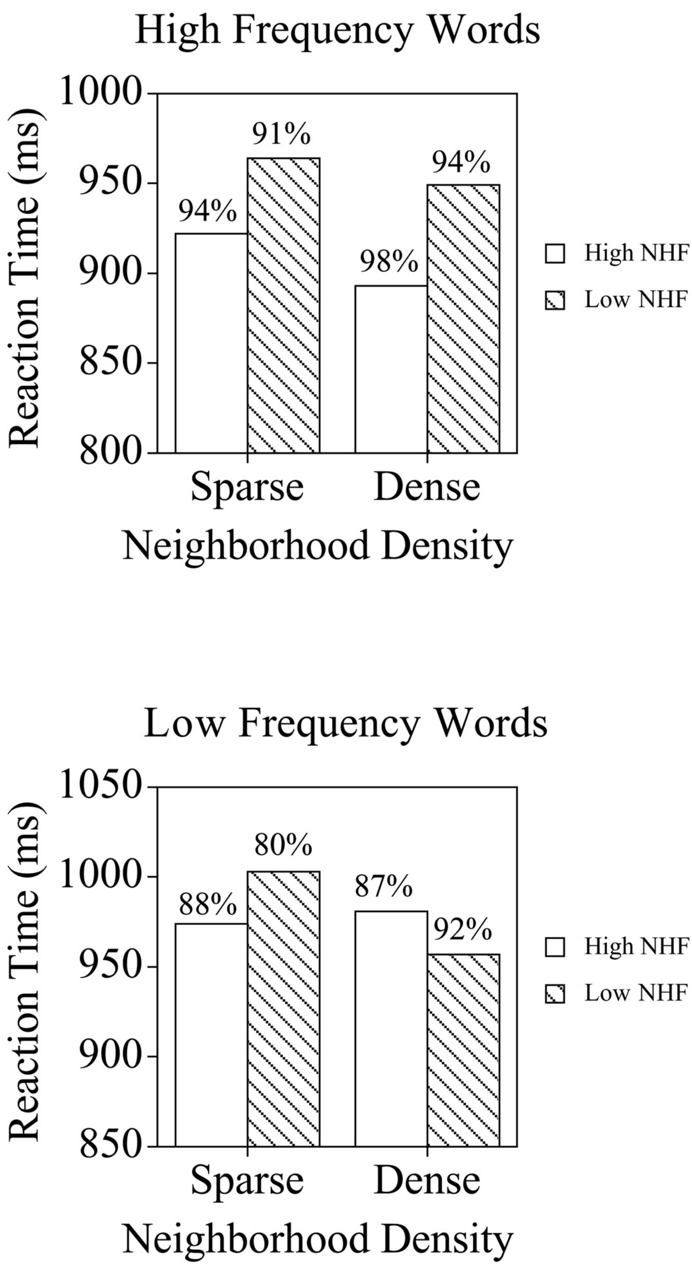

Figure 1. The mean reaction times and accuracy rates in the auditory lexical decision task.

accurately than low frequency words (mean = 87%), again, replicating previous studies. A main effect of neighborhood density was found ($F(1,36) = 13.08$): words with dense neighborhoods (mean = 93%) were responded to more accurately than words with sparse neighborhoods (mean = 88%). As with the reaction times, this result is the opposite of what is observed in English (Luce, & Pisoni, 1998). A main effect of neighborhood frequency was found ($F(1,36) = 19.68$): words with high frequency neighborhoods (mean = 92%) were responded to more accurately than words with low frequency neighborhoods (mean = 89%); also contrasting with what is observed in English (Luce, & Pisoni, 1998).

A significant two- and three-way interaction was also found for accuracy rates. The two-way interaction involved neighborhood density and neighborhood frequency ($F(1,36) = 13.27$). Among words with dense neighborhoods, there was no difference between words with high neighborhood frequency (mean = 92%) and words with low neighborhood frequency (mean = 93%). However, sparse words with high neighborhood frequency (mean = 91%) were responded to more accurately than dense words with low neighborhood frequency (mean = 85%; $F(1,36) = 22.47$). None of the other two-way interactions were significant (even at $p < 0.05$).

As in the analysis of response latency, the significant three-way interaction in the accuracy rates was due to the response patterns found among low frequency words with dense neighborhoods. Pair-wise comparisons showed that low frequency words with dense, high frequency neighborhoods (mean = 87%) were responded to less accurately than low frequency words with dense, low frequency neighborhoods (mean = 92%; $F(1,36) = 5.49$, $p < 0.05$). As in the pattern for the reaction times, this pattern is the opposite of the other conditions displayed in Figure 1. Pair-wise comparisons showed that low frequency words with sparse, high frequency neighborhoods (mean = 88%) were responded to more accurately than low frequency words with sparse, low frequency neighborhoods (mean = 80%; $F(1,36) = 18.46$). Additional pair-wise comparisons showed that the other conditions were not significantly different, but tended to be in the opposite direction: high frequency words with dense, high frequency neighborhoods (mean = 98%) were responded to more accurately than high frequency words with dense, low frequency neighborhoods (mean = 94%; $F(1,36) = 3.32$; $p = 0.08$); high frequency words with sparse, high frequency neighborhoods (mean = 94%) were responded to more accurately than high frequency words with sparse, low frequency neighborhoods (mean = 91%; $F(1,36) = 2.91$; $p = 0.09$).

Discussion

The results of the present experiment showed that high frequency Spanish words are responded to more quickly in an auditory lexical decision task than low frequency Spanish words. This result is consistent with previous studies of spoken word recognition in English (Luce, & Pisoni, 1998). Contrary to our predictions, however, words with dense neighborhoods were responded to more quickly and accurately than words with sparse neighborhoods. Similarly, the results for neighborhood frequency were the opposite of what is typically found in English (Luce, & Pisoni, 1998). In the present experiment, we found that Spanish words with high neighborhood frequency were responded to more quickly and accurately than words with low neighborhood frequency. These findings are—to the best of our knowledge—the first to demonstrate that neighborhood density and neighborhood frequency influence *spoken* word recognition in Spanish.

More interesting, the results of the present experiment suggest that the influence of neighborhood density in spoken word recognition in Spanish may be different from the influence of neighborhood density on spoken word recognition in English (Luce, & Pisoni, 1998), despite similar relationships among neighborhood density, word frequency, etc. in Spanish and English. Presumably, the goal of spoken word recognition in any language is to process information as accurately and efficiently as possible. The manner in which these goals are achieved may depend on the characteristics of the words in that language. If long words place different demands on processing than short words (e.g., Wiener, & Miller, 1946), then neighbors that are also long words might place different demands on the recognition system than short words that are neighbors of short words. Consider that Vitevitch and Luce (1999; see also Cluff, & Luce, 1990) found evidence for different processes being employed to recognize mono- versus bi-syllabic words that varied in neighborhood density in English. Perhaps these ''alternative'' processes in English are the default processes in languages that typically have longer words than those found in English.

Given the many differences that exist among the languages of the world, it is perhaps not surprising that differences in processing are observed across languages. Compare the different segmentation strategies that might be employed in stress-timed languages like English (Cutler, & Norris, 1988) versus syllable-timed languages like French (Mehler, Dommergues, Frauenfelder, & Segui, 1981). Cross-linguistic differences may also account for some differences observed in vocabulary acquisition (Kim, McGregor, & Thompson, 2000). As a result of such differences among languages, language disorders may present themselves in a different way in other languages. For example, Paulesu et al. (2001) found, using PET, that French, English, and Italian individuals with dyslexia had less activation in several regions in the left hemisphere than nondyslexic individuals. However, the prevalence of dyslexia among English speakers is twice the rate of dyslexia among Italian speakers. Paulesu et al. suggested that the deeper orthography in English relative to the much shallower orthography in Italian might account for the differences observed in reading performance across the two languages. Indeed, Goswami (2003) found that phonemic awareness and grapheme-to-phoneme recoding develops relatively efficiently in children that learn to read languages with consistent orthographies (i.e., close to a one-to-one mapping between sounds and letters). Such children tend to show reading deficits that are mainly speed-based. In contrast, children learning to read a language with an inconsistent orthography have poorly developed phonemic awareness and grapheme-to-phoneme recoding. Moreover, such children show deficits related to both speed and accuracy in diagnostic phonological and literacy tasks. Future research in our lab will examine the influence of neighborhood density across words of different lengths within a language, as well as across languages to better determine how phonological similarity may differentially affect processing in different languages, and affect language disorders in different languages.

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Notes

1 Neighborhood density refers to the number of words that are similar to a target word (Luce, & Pisoni, 1998). Words with many similar words, or neighbors, are said to have a dense neighborhood, whereas words with few neighbors are said to have a sparse neighborhood.

2 This subset was selected because information on all of the variables of interest could be found for only these items. Familiarity ratings were not provided for all of the words in the database. This greatly constrained our analysis.

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