Syllable-frequency effects in visual word recognition: evidence from ERPs

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A lexical decision experiment was conducted while event related potentials (ERPs) were recorded. The word frequency and the first syllable frequency of each word were manipulated. Results showed that, while high frequency words produced less negative amplitudes in the N400 time window than low frequency words, the inverse pattern was found for syllable frequency. Words containing high frequency syllables produced more negative amplitudes than words containing low frequency syllables. Importantly, a significant syllable frequency effect was also obtained at the P200 time window. The results are interpreted in the framework of an interactive activation model, in which high frequency syllables produce the initial activation of a larger number of lexical candidates during the analysis of orthographic or phonological representations, which have to be inhibited later to allow the identification of a unique word. These findings support the idea that, at least in languages with clear syllabic boundaries, syllables are functional sublexical units during visual word recognition. *NeuroReport* 15:545–548 © 2004 Lippincott Williams & Wilkins.

Key words: ERP; Language; Lexical access; N400; P200; Syllable; Word frequency

INTRODUCTION

The syllable has been proposed as a sublexical unit during visual word recognition [1–9]. However, other researchers have argued that there is no need to postulate intermediate representations between orthographic and lexical units, as the co-occurrence of specific letter sequences in a particular language would make the processor sensitive to specific orthographic and phonological patterns [10].

Evidence in favor of syllabic processing during visual word recognition has been obtained especially in languages with clear syllable boundaries and transparent orthography. A number of experiments have found that syllable frequency influences response times to words in Spanish [1,2,7], and the effect has recently been replicated in French [6] and in German [4]. The main finding is that words with high-frequency syllables produce longer latencies than words with low-frequency syllables in lexical decision tasks (deciding if a letter string is a word or not). This inhibitory effect of syllable frequency has been interpreted in terms of competition at the word level in an interactive activation model [1,2,7]. The basic assumption is that not only orthographic neighbors (i.e. words that share all letters but one, e.g. cosa/casa; the Spanish for thing/house) are being activated in the process of visual word recognition, but also syllabic neighbors (i.e. words that share a syllable, e.g. cosa/codo; thing/elbow). Thus, more inhibitory connections between lexical units would be established in the case of words with many syllabic neighbors than with few syllabic neighbors, and therefore more suppression activity would be needed from the target item in tasks in which resolution of the candidate set is needed, such as the lexical decision task [2]. It is worth noting that a number of other potential explanatory factors of the syllable frequency effect have been discarded: neither bigram frequency [2], orthographic neighborhood size/frequency [1,7], nor morpheme frequency [1] can account for the previous findings. Thus, the syllable frequency effect suggests that the syllable is a fundamental processing unit in visual word recognition in Spanish and other languages. The goal of the present experiment is to examine the role of the syllable in lexical access by analyzing the impact of the syllable frequency on electrophysiological measures. ERPs are voltage changes recorded from the scalp and extracted from the background electroencephalogram by averaging time-locked responses to stimuli onset. Of specific interest for our study is the N400 component, a negative deflection occurring around 400 ms after a word presentation, that has been associated to lexical-semantic processing [11,12]. In particular, the amplitude of this negativity is an inverse function of the lexical frequency, this amplitude being greater for low frequency words than for high frequency words [13,14]. In the present experiment, participants were presented with a list of Spanish words and pseudowords (i.e., letter strings that resemble real words but do not violate the phonological and orthographic rules of the language) and had to make lexical decisions. Frequency of words and frequency of the first syllable of the words were manipulated in a factorial design, while neighborhood size (number of orthographic neighbors) and bigram frequency (frequency of co-occurrence of letters) were maintained constant. Recently, Holcomb *et al.* [12] analyzed the influence of orthographic neighborhood size on the N400 amplitude. Words embedded in a large neighborhood generated larger N400s than words embedded in a sparse neighborhood. Holcomb *et al.* concluded that larger neighborhoods produce higher levels of activation, either at the level of form representations, or at the level of semantic representation. If syllabic neighbors behave much in the same way as orthographic neighbors, then syllable frequency should produce a modulation of the amplitude in the same direction as neighborhood size. Therefore, an increase of amplitude in the N400 for words containing high frequency syllables as compared to those containing low frequency syllables could be predicted, and in contrast, a reduction of this component for high frequency words as compared to low frequency words.

MATERIALS AND METHODS

Participants: Thirty university students (20 women), aged 18–25 years (mean 20.09. years), who were native Spanish speakers and right-handed, took part.

Stimuli: A list of 200 di-syllabic words, all of them of four or five letters, was selected from a Spanish standard corpus [15]. Half of them were of high word frequency and the other half of low word frequency. In addition, within each group of word frequency half contained a first syllable of high frequency and the other half a first syllable of low frequency (see Table 1). The structure of the first syllable was always a consonant followed by a vowel (CV structure). The frequency of the inter-syllable bigrams was always greater than the frequency of the intra-syllable bigrams. Orthographic neighborhood size, defined as the number of words that can be created by changing one letter of the stimulus item, preserving letter positions, was matched across conditions. All words were content words (nouns, verbs or adjectives) presented in singular form. No inflected forms were included. In addition, 200 pseudowords were created for the purposes of the lexical decision task. These pseudowords were matched with the experimental words in length, and their first syllable also presented a CV structure.

Procedure: Stimuli were presented at eye level 80–90 cm in front of the participant in black lower-case letters against a grey background. Participants were required to indicate, as quickly as they could, whether each letter string was a word or not by pressing a response button positioned beneath each thumb. The sequence of events in each trial is described as follows. First, a fixation point (+) appeared in the centre of the screen and remained there for 2000 ms. This fixation point was followed by a blank screen interval of 200 ms, and then a word or a pseudoword appeared and remained there up to a maximum of 1500 ms or until the response of the participant. The inter-trial interval varied randomly between 250 and 750 ms. The stimuli were presented in different random order for each participant.

Data acquisition and analysis Scalp voltages were collected from Ag/AgCl electrodes using a 128-chanel Geodesic Sensor Net (Fig. 1). The vertex electrode was used as reference, and the recording was re-referred off-line to a linked mastoids reference. Eye movements and blinks were monitored with supra- and infra-orbital electrodes and with electrodes in the external canthi. Inter-electrode impedances were kept below 30 kΩ (amplifier input impedance >200 MΩ). Electro encephalogram was filtered with an analogue bandpass filter of 0.01–100 Hz (50 Hz notch filter) and a digital 30 Hz low-pass filter was applied before analysis. The signals were digitally sampled at 250 Hz. Epochs corresponding up to 500 ms after word onset presentation were averaged and analyzed. Baseline correction was performed using the average activity in the 100 ms preceding the word onset. Epochs with simultaneous artifacts in ≥ 10 channels were rejected. This operation resulted in the exclusion of $< 10\%$ of the trials, which were evenly distributed along the different conditions. Furthermore, electrodes with a high level of rejected trials ($> 10\%$) were substituted by the average value of the group of nearest electrodes.

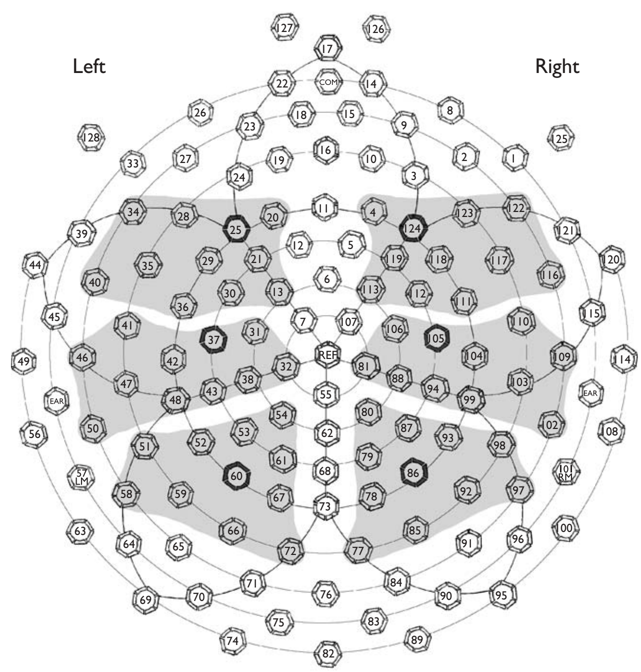

Fig. 1. Schematic flat representation of the electrode positions (front of head is at top), and 6 electrode groups used in the statistical analysis. Marked sites correspond with electrodes plotted in Fig. 2 and Fig. 3.

Table 1. Mean values (/10^6) of first syllable frequency, lexical frequency and number of orthographic neighbors for the words presented in each experimental condition.

	High syllable frequency		Low syllable frequency	
	High word frequency	Low word frequency	High word frequency	Low word frequency
First syllable frequency	3169	2195	360	198
Lexical frequency	99	4.1	63	3.3
Orthographic neighbors	10.6	6.6	8.3	6.1

Syllable frequency refers to the number of times that each syllable appears in the Spanish corpus. Lexical frequency refers to the number of times that each word appears in the Spanish corpus. Number of neighbors refers to the number of words that can be created by changing one letter of the stimulus words preserving letter positions.

Statistical analyses were carried out on the basis of calculations of mean amplitudes of groups of electrodes (Fig. 1) in two temporal windows: 150–300 and 350–500 ms. Different repeated measures ANOVAS were performed, including as factors electrode region (anterior, central and posterior), hemisphere (left and right), syllable frequency (high *vs* low) and word frequency (high *vs* low). In cases of interaction of syllable frequency and/or word frequency with the electrode region or hemisphere, data were normalized following the vectorial scaled procedure recommended by McCarthy and Wood [16]. Where appropriate, critical values were adjusted using the Geisser–Greenhouse correction for violation of the assumption of sphericity [17].

RESULTS

Grand average waveforms are plotted in Fig. 2 and Fig. 3. All conditions showed the N1-P2 complex followed by a negative deflection that fits with the N400 component. Figure 2 shows the word frequency effect. High frequency words have a smaller N400 component associated than low frequency words. The inverse pattern was observed for the syllable frequency effect, as is shown in Fig. 3. High frequency syllables produced greater (more negative) amplitudes than low frequency syllables in the N400 time window. Both effects presented similar slightly anterior distribution over the scalp. We should also note that the onset of the syllable frequency effect starts as early as 150 ms, appearing at the P200 component time-window.

In the 150–300 ms time window, the ANOVA resulted in a significant two-way interaction between syllable frequency and electrode region ($F(2,28)=3.77$; $p<0.05$; $\epsilon=0.59$), and this interaction was confirmed after data normalization ($F(2,28)=4.44$; $p<0.05$; $\epsilon=0.67$). *Post-hoc* tests showed that syllable frequency was significant in both left and right anterior areas ($F(1,29)=7.5$; $p<0.01$ and $F(1,29)=8.75$; $p<0.01$, respectively), as well as in the right central area ($F(1,29)=4.53$; $p<0.05$) and marginally significant in the left central area ($F(1,29)=2.95$; $p=0.09$) but not in the posterior areas ($F<1$). In the 350–500 ms time window, the ANOVA revealed a main effect of word frequency ($F(1,29)=7.70$; $p<0.05$), and a main effect of syllable frequency ($F(1,29)=12.06$; $p<0.005$). The was also an interaction between syllable frequency and the electrode region factors ($F(2,28)=4.13$; $p<0.05$; $\epsilon=0.66$), but in this case the effect was only marginally significant when data were normalized ($F(2,28)=2.87$; $p=0.09$; $\epsilon=0.59$). Additional ANOVAS over shorter time epochs of 50 ms confirmed that, while word frequency effect was not significant until the 350–400 ms time window, the syllable frequency effect was already significant at 150–200 ms ($p<0.05$).

DISCUSSION

ERPs associated to high frequency words produced an amplitude reduction of the N400 component compared with low frequency words, confirming previous reports [13,14]. More importantly, the syllable frequency showed the reverse pattern. Words containing high frequency syllables produced an increase of the N400 amplitude, showing more negative amplitudes than words containing low frequency syllables. Similarly, Holcomb *et al.* [12] found a direct correlation between the orthographic neighborhood size and the N400 amplitude, interpreting that words with many orthographic neighbors produce a greater activation than words with less

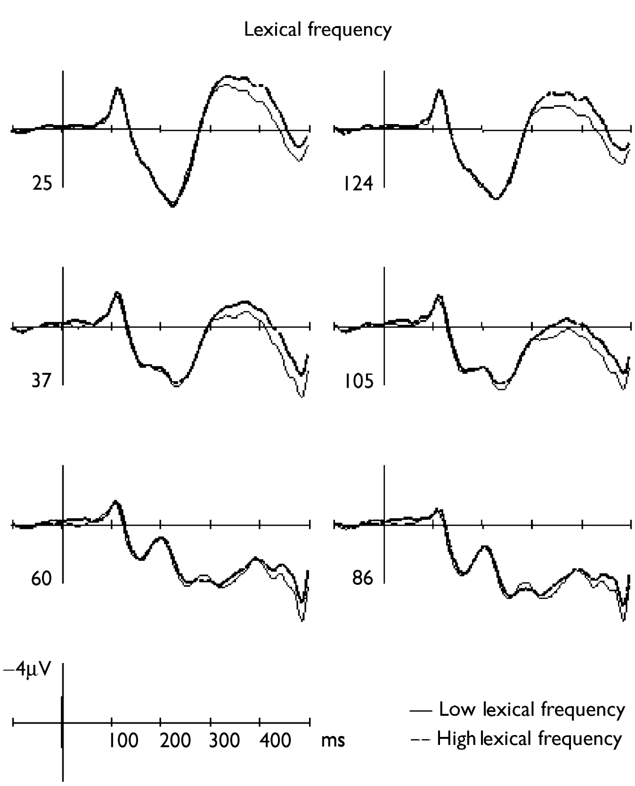

Fig. 2. Grand averaged waveforms corresponding with high and low frequency words (words with high and low frequency syllables collapsed) at 6 representative electrodes.

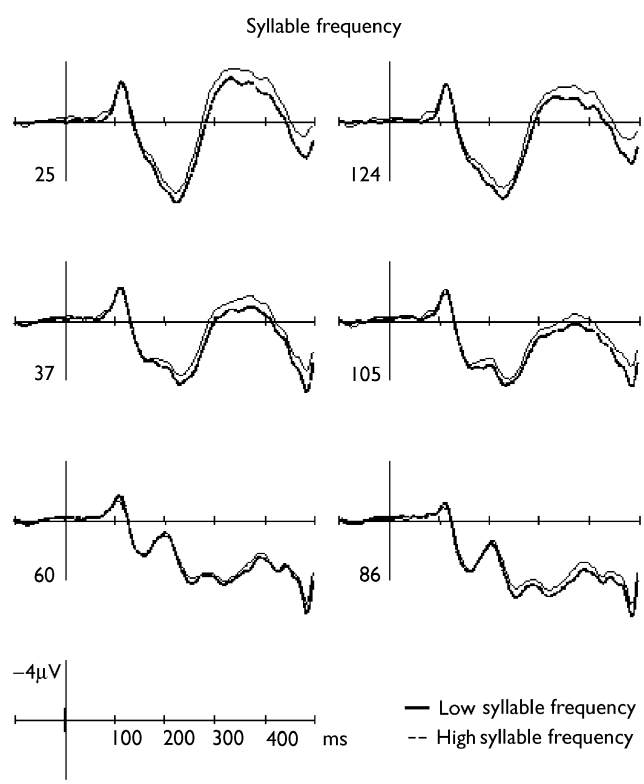

Fig. 3. Grand averaged waveforms corresponding with words with high and low frequency syllables (high and low frequency words collapsed) at 6 representative electrodes.

neighbors. Our results can be explained by a similar underlying process of lexical activation. However, notice that orthographic neighborhood was matched in our stimuli, so the effects cannot be attributed to this variable, but to syllable frequency. It has been proposed [2] that when the Spanish word cosa (thing) is read, words that share the syllable 'co' (as codo [elbow]) would be initially activated as possible lexical candidates. High-frequency syllables would trigger a larger number of lexical candidates because they are shared by a larger amount of words. Thus, high frequency syllables would produce more lexical activation than low frequency syllables.

Another important finding is the early onset of the syllable frequency effect. While the word frequency effect started around 350 ms from onset, the syllable frequency effect started as early as 150 ms, appearing at the P200 component time-window. The onset difference between the two effects, which has also been obtained in other experiments where syllabic structure and word frequency were manipulated (unpublished observations), suggests that they could be associated with different stages of lexical access. While the word frequency effect could be reflecting lexical access, the syllable frequency effect could be associated with a phonological processing of the stimuli and the activation of lexical candidates. Moreover, the onset difference of the two effects allows us to entertain the idea that the N400 is not (only) reflecting lexical activation. To identify the correct word, the other candidates should be inhibited, via lateral inhibition, in a selection stage [3]. Thus, it could be the case that the differences found in the N400 could be produced not only by the activation of the candidates, process which could have started earlier, but also by the lateral inhibition process. Words with many syllabic neighbors not only produce more activation, but the process of lateral inhibition that is needed to suppress the activity of other items is more effortful in the case of words from larger orthographic/syllabic neighborhoods. It is important to note that the present results cannot be accounted for by the orthographic redundancy hypothesis [10], according to which syllabic effects are explained by the transition probability of letter sequences. Syllabic boundaries tend to be bigrams of lower frequency than those bigrams contained in the syllabic unit. However, in the present experiment, the intra-syllable bigram frequency was always lower than the inter-syllable bigram frequency. Thus, our findings reinforce the claim that syllables are functional processing units during visual word recognition [1–9]. On the one hand, the present results provide evidence converging with the behavioral experiments which have found that while word frequency produces a facilitative effect in lexical decision tasks, syllable frequency produces in an inhibitory effect (words with high-frequency syllables are identified more slowly than those with low-frequency syllables [1,2,4,6,7]). On the other hand, our findings suggest that high frequency syllables trigger more lexical activation than low frequency syllables, and hence that more effort is needed to suppress the other lexical candidates. Taken together, our results have important implications for current models of visual word recognition, which have focused on monosyllabic words, overshadowing the importance of sublexical units, such as the syllable. Thus, the present results represent a challenge for current models, which should be modified to be able to simulate these effects and in general to deal with the processing of polysyllabic words.

CONCLUSION

Our data show a modulation of ERP amplitudes starting around 150 ms depending on the syllable frequency. This effect, together with the later effect of syllable frequency on the N400 is in line with the proposal that syllables trigger the activation of lexical candidates during the analysis of orthographic or phonological representations, which are inhibited later, to allow the identification of a unique word. Therefore, these findings support the idea that, at least in languages with clear syllabic boundaries, syllables are functional sublexical units during visual word recognition, and they call for a modification of the current models.

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