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Syllable-frequency effect in visual word recognition: Evidence of sequential-type processing

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Three experiments examine the syllable-frequency effect during visual word recognition in Spanish. Disyllabic words and pseudowords were employed manipulating the positional frequency of the first and the second syllable as well as the word frequency (only for words). A standard lexical decision task (Experiment 1) and a temporal separation technique (Experiments 2 & 3), in which either the first or the second syllable acted as a prime of the whole stimulus were used, measuring reaction times and errors. The results replicated the inhibitory effect of syllable-frequency obtained in several previous experiments in Spanish and offer support for an activational model incorporating a syllabic level. However, this type of model must incorporate sequential properties: both syllables activate lexical representations but they do not play exactly the same role, indicating a bias toward the first syllable. The implications of the findings for the notion of a sequential-type processing are discussed.

Key words: visual word recognition, lexical access, syllable frequency.

Some models of visual word recognition have claimed that some kind of sublexical analysis or decomposition of the stimulus/input is necessary in order to reach the lexical access, at least in multisyllabic words (e.g., Forster, 1976; 1989; Taft, 1991; Tousman & Inhoff, 1992). What sublexical units are entailed in this association of the input with the mental representation and what processes are involved, have been object of discussion for more than 20 years.

Several sublexical structures have been proposed as functional units of encoding: morphemes (Gibson & Guinet, 1971; Murrell & Morton, 1974; Rapp, 1992; Taft & Forster, 1975), Basic Orthographic Syllabic Structure -BOSS- (e.g. Taft, 1979), word body (Kay & Bishop, 1987; Patterson & Morton, 1985) and, recently, the body of the BOSS (Forster & Taft, 1994; Taft, 1992). Among

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these proposals, the syllable has been one of the sublexical units which has received a greater attention (e.g., Ferrand, Seguí & Grainger, 1996; Lima & Pollatsek, 1983; Millis, 1986; Printzmetal, Treiman & Rho, 1986; Rapp, 1992; Rapp, Alway & Caramazza, 1993; Spoehr & Smith, 1973; Taft & Forster, 1976; Tousman & Inhoff, 1992). In addition, several syllable-related structures have also been proposed. Vocalic Center Groups -VCG- (Hansen & Rodgers, 1968; Spoehr & Smith, 1973) and subsyllabic components, as onset and rime (e.g., Treiman & Chafetz, 1987; Treiman, Mullennix, Bijeljac-Babic & Richmond-Welty, 1995), are good examples.

Despite the vast amount of experimental evidence about the role of the syllable in lexical access, some authors disagree with the notion that words are parsed into syllables (Adams, 1981; McRae, Jared & Seidenberg, 1990; Seidenberg, 1987; 1989). According to Seidenberg, for instance, sublexical units are only the by-products of a parallel activation process, and the syllabic effects reported in the literature should be understood as deriving from the frequency of co-occurrence of letter patterns (e.g., high-frequency bigrams within syllables and low-frequency bigrams between syllables). However, some studies have shown reliable effects of syllabic structures which cannot be accounted for by the presence or absence of the so-called *bigram troughs* (Carreiras, Álvarez & de Vega, 1993; Rapp, 1992).

Most of the empirical arguments against the role of syllable in visual word recognition have been found in English and, consequently, the theoretical discussion has also focused on English-based research. However, languages differ in their phonological and orthographic characteristics, for instance in the definition of syllable boundaries. English is a language with ambiguous and ill-defined syllable boundaries. There is no single accepted theory of how words are syllabified and the syllable boundaries tend to be modified by stress (Sánchez-Casas, 1996) Syllabification in this language is affected by several factors, such as morphological structure (Selkirk, 1982; Treiman & Danis, 1988; Treiman & Zukowski, 1990). Additionally, the ambisyllabicity and resyllabification phenomena are common. In contrast, other languages like Spanish have well-defined syllable boundaries (Harris, 1983; Sánchez-Casas, García-Albea & Bradley, 1991) that are resistant under stress movement (Sánchez-Casas, 1996) and there is nearly no ambisyllabicity. In fact, simple computer programs have been developed and used in order to segment words into their syllables automatically (e.g. Cobos, Domínguez, Álvarez, Alameda, Carreiras & de Vega, 1995). Consequently, we may expect that skilled readers in English and Spanish have developed different processes to recognize a word, at least in the sublexical levels of the analysis of the stimulus.

In particular, there is considerable evidence about the role of syllables in visual word recognition in Spanish. García-Albea (1991) proposed that Spanish readers use syllabic segmentation in lexical access. He presented subjects with segmented words (e.g. *mo neda*) and pseudowords in a lexical decision task and found more facilitation for segmentation coinciding with phonological syllable than for segmentation coinciding with orthographic syllable (BOSS). This result is the opposite to that obtained by Taft (1979) in English, using the same task, although Lima and Pollatsek (1983) did not find any advantage for BOSS over phonological syllable in English either.

Most of the evidence supporting the syllable as a functional unit while reading in Spanish has been obtained in experiments that manipulated syllable frequency. In a first study, de Vega, Carreiras, Gutiérrez and Alonso (1990), using a moving window task with self-paced reading, found that reading times for words embedded in texts were negatively related to the positional frequency of their syllables. The positional syllable frequency was a token recount of the number of times that a syllable appears in a particular position in a word (first, second, etc.), in a corpus of printed Spanish. Since the positional syllable frequency is the factor we are interested in, we will refer to it only as "syllable frequency" (SF) henceforth. Similar results were obtained in other studies using lexical decision task (de Vega & Carreiras, 1989; Domínguez, Cuetos & de Vega, 1993): words with high-frequency syllables produce longer reaction times (RTs) than words having low-frequency syllables. Similar counterintuitive results have also been found in English although associated to the frequency of letter clusters rather than SF (Broadbent & Gregory, 1968; Grainger & Jacobs, 1993; McClelland & Rumelhart, 1981).

Carreiras, Álvarez and de Vega (1993) used a larger dictionary of SF in Spanish (Álvarez, Carreiras & de Vega, 1992) to select the experimental items. In their Experiment 1, using a lexical decision task, they found clear SF effects, both in disyllabic and trisyllabic words. Again, words having high-frequency syllables produced longer RTs than words with low-frequency syllables. Furthermore, the orthographic redundancy hypothesis (Seidenberg, 1987; 1989) was tested. A new set of only disyllabic stimuli were selected, which did not exhibit any trough pattern although SF differed in high and low (Exp. 3). The bigram (pairs of letters) frequency was held constant within and between syllables. Bigram and SF were manipulated orthogonally in pseudowords. They found reliable effects of word frequency and, more important, reliable effects of SF (after controlling for bigram frequency. However, it is important to mention that the syllable-frequency effect was bigger for low-frequency words. In addition, SF was significant in pseudowords producing an inhibitory effect as well, while bigram frequency was not. These results cannot be accounted for by Seidenberg's orthographic redundancy hypothesis and they support the idea that letter-clusters frequency cannot explain by itself the effect of SF. Carreiras et al. concluded that syllables are access units in visual word recognition in Spanish (and perhaps in other languages with a clear syllabic structure). They also suggest that the syllabic effect could be explained within the framework of a PDP-type model including the syllable as a sublexical unit of processing. High-frequency syllables would activate a larger set of lexical candidates (or syllabic neighbors) than low-frequency syllables. They presumed that it takes more time to select a word from a large set than from a small one. Thus, it will take longer to select a word with high-frequency syllables than a word with low-frequency syllables. The mechanism of mutual inhibition among activated word nodes would provide, according to the authors, an accurate account of the results. This assumption was studied by Domínguez, de Vega and Cuetos (1997) employing priming tasks. They compared pairs of words (prime-target) in which the first two or three letters matched. In the syllabic condition, the prime and the target shared the syllabic boundaries (e.g. *nor/ma-nor/te)* while in the orthographic condition they shared the same initial letters although differed in syllabic boundaries (e.g. *no/ria-nor/te*). They found longer RTs for the syllabic condition than for the orthographic (but not syllabic) condition, suggesting that the lexical process of the prime inhibited the target when both belonged to the same syllabic cohort. Similarly, Carreiras and Perea (submitted) found inhibitory masked-priming effects when prime and target shared the initial syllable compared with a control condition. Additionally, the effect is clear only when the prime is of higher frequency than the target. According to the authors, the explanation of such result is that high-frequency primes produces lexical inhibition over its syllabic neighbors of lower frequency (including the targets).

Several experiments have also demonstrated that SF effects cannot be explained by other factors which correlate with it, as orthographic neighborhood (words that share one syllable with the stimulus). Perea and Carreiras (1998) found robust inhibitory effects of SF and word frequency when controlling orthographic neighborhood using a lexical decision task. They also found that the effect of SF was bigger in low-frequency words. They concluded that "future research should take into account the inhibitory effects not only from higher frequency orthographic neighbors (e.g. Grainger, 1990; 1992; Grainger & Seguí, 1990) but also from syllabic neighbors (i.e. words that share a syllable with the target)" (Perea y Carreiras, 1998, p. 142; see also Carreiras, Perea & Grainger, 1999). According to Perea and Carreiras, models as PDP (Seidenberg & McClelland, 1989) or the Interactive-Activation model (McClelland & Rumelhart, 1981) should be modified to include subword level representation such as syllables (see also Ferrand et al., 1996; Rapp, 1992; Taft, 1991; Tousman & Inhoff, 1992), at least in languages with clear syllabic boundaries, such as Spanish. But the main contribution of that study was that the syllable-frequency effect is caused by the number of higher frequency syllabic neighbors, that is, words that share one syllable with the stimulus and have a higher frequency, instead of by the number of syllabic neighbors *per se*. In addition, Álvarez, Carreiras and Taft (in press), in a recent research have showed that the SF effect is still observable when controlling for BOSS frequency and that it cannot be explained by morphological (stem) frequency either, which also influences lexical access but in a independent way.

To sum up, there is a considerable evidence to assert that the frequency of the syllables influence visual word recognition in Spanish. However, there are a number of issues which remain unsolved. Most of the aforementioned studies (Carreiras et al., 1993; de Vega et al., 1990; de Vega & Carreiras, 1989; Domínguez et al., 1993) have calculated SF as the mean frequency of the two or three syllables integrating words or pseudowords, whereas other experiments have dealt with the SF of just the first syllable (Álvarez, Carreiras & Taft, in press; Perea & Carreiras, 1998). Even though the general role of syllable as an activational unit in lexical access seems to be clear, it is less apparent whether all syllables within a word have the same importance in word processing. That is, if all syllables within a word (first, second...) have the same role in activating lexical candidates, or if the first one plays a dominant role, as some studies have pointed out (Taft & Forster, 1976; Tousman & Inhoff, 1992; see also Grainger, O'Regan, Jacobs & Seguí, 1992; Perea & Gotor, 1991, for initial letters). Only a study by Álvarez, de Vega and Carreiras (1998) addressed this issue using trisyllabic stimuli but the results were not conclusive: whereas inhibitory frequency effects were observed in the three syllables in pseudowords, only in some experiments a first-syllable frequency effect was observed in words. The tendency of the second-syllable frequency in words was facilitatory.

According to PDP-type models and other activational models of visual word recognition (e.g. McClelland & Rumelhart, 1981; Paap, Newsome, McDonald & Schvaneveldt, 1982; Seidenberg & McClelland, 1989), all letters (and by extent, all syllables) in a word are processed simultaneously (although not necessarily to the same extent), with no sequential-like properties. However, it is important to remark that PDP-type models have been limited to monosyllables although Jared and Seidenberg (1990) have argued that multisyllabic words are recognized holistically with no syllabic level of representation (see a contrary point of view in Tousman & Inhoff, 1992).

By contrast, several proposals have argued that there is some kind of superiority of word beginnings over word endings. For instance, Forster's search model (1976; 1989; Taft & Forster, 1976) claims that the initial letters (grossly, the first syllable) of a word act as an access code which is responsible for the selection of the correct "bin" (those word units which share the same access code). According to Taft and Forster (1976), the first syllable allows access to the lexicon in multisyllabic words. In the same vein, Tousman and Inhoff (1992) proposed a dual-route model in which the first syllable has the role of activating lexical representations, but only in the case of low-frequency multisyllabic words, which are recognized via syllabic representations.

Others have suggested that word beginnings play a privileged role in visual word recognition, via eye fixation bias toward initial letters (Briihl & Inhoff, 1995; Lima & Inhoff, 1985; O'Regan & Jacobs, 1992; O'regan, Lèvy-Schoen, Pynte & Brugaillère, 1984; Rayner, 1979; Rayner, Well, Pollatsek & Bertera, 1982) or via assigning greater weights to the connections between initial letters and word nodes than to the connections between end letters and the same representations (Grainger, O'regan, Jacobs & Seguí, 1992; Grainger & Jacobs, 1993; Inhoff & Tousman, 1990). Although these proposals share the assumption of some kind of sequentiality or processing with differential weighting in word reading, they differ in the specific mechanism: in one case the difference between word beginnings and word endings is qualitative and sequential (e.g. Taft & Forster, 1976) and in the other case is quantitative (e.g. Grainger et al., 1992). We will refer to the latter quantitative point of view as “sequential-type” or “sequential-like” processing, since the assumption of units as syllables unequally weighted does not imply sequentiality strictly speaking.

Assuming that the syllable is an important unit in visual word recognition, at least in Spanish, the experiments reported here represent a test of the two alternative explanations of the syllable-frequency effect that were discussed earlier: 1) there is a bias toward the initial syllable, involving some sort of sequential-type processing, or 2) both syllables have the same role in activating lexical candidates. We think that there are enough evidence favoring the sequentiality hypothesis in the literature, although this issue has not been investigated in the case of the SF effect. Thus, we predict that some trace of superiority of the first syllable should be found. In Experiment 1, we will test the two possibilities (is there a bias toward the first syllable or do both syllables have the same weight?) by manipulating orthogonally the positional SF of both syllables in disyllabic words and pseudowords, as well as the word frequency. Experiments 2 and 3 were designed to clarify this issue and to obtain some evidence about the nature of the sequential mechanism by using the temporal separation technique (Lima & Pollatsek, 1983; Perea & Gotor, 1991; Sánchez-Casas et al., 1991; Taft, 1987), presenting first or second syllable as a prime of the whole stimulus.

EXPERIMENT 1

In previous experiments, SF has been manipulated either as the mean frequency of the two syllables in disyllabic words and pseudowords (e.g., Carreiras et al., 1993) or just as the frequency of the first syllable in words (Perea & Carreiras, 1998). Although it seems clear that the frequency of the first syllable has an important inhibitory[i] influence on performance, it has not been possible to conclude anything about subsequent syllables. They can play either a similar role, as a totally-parallel model would predict, or a negligible role, according to models based on the first part of the word. To put another way, is the first syllable the only one that plays the role of activating the lexical candidates, or do the two syllables play the same activating function? Moreover, pseudoword data will also provide information about the locus of the syllable-frequency effect: is it a prelexical effect or not ? These are the main goals of this experiment.

In order to obtain a more accurate view of the syllable-frequency effect, we manipulated the frequency of the two syllables orthogonally, both in disyllabic words and pseudowords.

METHOD

Participants. Forty undergraduate students from the University of La Laguna who received course credit for their participation.

Stimuli. Sixty-four disyllabic words, four to five letters long, were selected according to the orthogonal combination of three factors: 1) Frequency of the first syllable (high versus low), 2) Frequency of the second syllable (high versus low), and 3) Word frequency (high versus low). Syllables were selected according to their token frequency in the dictionary of SF in Spanish which was made over 25,000 words (Álvarez, Carreiras & de Vega, 1992). The range for high-frequency syllables was from 125 to 925 (mean, 302, and SD, 160) and the range for low-frequency syllables, either in the first or in the second position, was from 2 to 60 (mean, 26, and SD, 16). On the other hand, words were selected according to their printed frequency in the Juilland and Chang-Rodríguez (1964) 500,000-words dictionary of frequency. The range for high-frequency words was from 60 to 725 (mean, 189, and SD, 135) and for low-frequency words was from 1 to 35 (mean, 12, and SD, 8). Besides length, there were two variables which were controlled: stress position (always on the first syllable) and word class (all the words were nouns or adjectives).

In addition, 64 pseudowords were constructed having only acceptable syllables in Spanish and matching their length, number of syllables and stress position with the real words. Two factors were manipulated in the pseudoword material: 1) High versus low frequency of the first syllable, and 2) High versus low frequency of the second syllable, matching the limit values for high and low frequency with those of words.

Procedure. The participants had to pay attention to a string of letters (words and nonwords) presented on the center of a computer screen in lowercase letters and they had to make a lexical decision as quickly and accurately as possible. The experiment was controlled by an IBM-compatible PC. Each trial started with the presentation of a fixation point (an asterisk) for 600 ms, which was replaced by the stimulus centered on the same place where the asterisk was. The stimulus remained until participants responded by hitting one of two keys: L key when it was a word and the A key when it was a nonword (the L key was labeled "SI", that means YES in Spanish, and the A key was labeled "NO"). The next sequence followed after a 1-second delay. Eighteen practice trials were followed by the 128 experimental trials. Items (words and pseudoword) were presented at random order. The computer recorded subjects' responses and reaction times.

RESULTS

The mean reaction times (RTs) for correct responses and the average error rates were calculated separately across subjects and items, independently for words and pseudowords. Incorrect responses and correct responses below 300 ms and above 1500 ms (0.6% of the data) were excluded from the RTs analyses. One subject was eliminated from the analyses because his/her high percentage of errors.

Word analyses. In order to test if there would be some interaction between syllable-frequency and word frequency, mean RTs and percent errors *only* for word stimuli (see Table 1) were submitted to separate analysis of variance (ANOVAs), with word frequency (high vs. low), first-syllable frequency (high vs. low) and second-syllable frequency (high vs. low) as within-subjects but between-items factors.

Table 1. Mean reaction times (in ms) and percentage of errors (in parentheses) as a function of lexicality (words vs. pseudowords) and syllable frequency (1st & 2nd syllables) in Experiment 1.

	Syllable frequency (1st & 2nd)			
	1st High		1st Low	
Lexicality	**2nd High**	**2nd Low**	**2nd High**	**2nd Low**
High freq. words	592 (3.5)	579 (1.9)	587 (0.9)	576 (1.6)
Low freq. words	632 (5.8)	615 (2.6)	611 (0.9)	595 (2.2)
Pseudowords	707 (7.2)	669 (3.6)	688 (4.9)	659 (2.4)

The ANOVAs on RTs for words revealed a significant main effect of word frequency [$F1$ (1, 38) = 53.03, p < .001; $F2$ (1, 56) = 11.54, p < .001] high-frequency words being responded to faster than low-frequency words. The main effect of first-SF was also significant, but only in the subject analysis [$F1$ (1, 38) = 7.52, p < .01; $F2$ (1, 56)= 1.81]. Reaction times (RTs) were faster for words with low-frequency first syllable (LF1 WORDS) than for words with high-frequency first syllable (HF1 WORDS). Second-SF was also significant only when subjects were treated as a random factor [F1 (1, 38) = 8.95, p < .005; $F2$ (1, 56)= 3.09]. Again, words with low-frequency second syllable (LF2 WORDS) showed faster reaction times than words with high-frequency second syllable (HF2 WORDS). Although no interaction produced reliable effects, it is important to mention the case of word frequency x first-SF [$F1$ (1, 38)=3.87, p =.056; $F2$ (1, 56)= .87] where the difference between high and low first-SF is quite bigger in low-frequency words (a difference of 20 ms) than in high-frequency words (only 3 ms).

The analysis of error rates (see Table 1) showed a main effect of first-SF [$F1$ (1,38) = 8.58, p < .01; $F2$ (1, 56) = 7.25, p < .01] HF1 words producing more errors than LF1 words, and a non-significant effect of second-SF. Moreover, the interaction between first-SF and second-SF was also significant [$F1$ (1, 38) = 9.01, p < .005; $F2$ (1, 56) = 5.11, p < .05], locating the main contrast in words with high-frequency first-syllable, where there were more errors in words with high-frequency second-syllable (4.6 %) than in words with low-frequency second-syllable (2.2 %). No further effects were significant.

We decided to carry out a new set of analyses pooling the word frequency and analyzing words and pseudowords together. These conjoined analyses allowed us to check the possible differential syllable-frequency effect between the two types of stimuli, an information that will contribute to clarify what is the status of each syllable-frequency in the process of word recognition. These analyses will also offer information about the locus of the effect (e.g. is it prelexical or is it purely lexical or postlexical ?).

Conjoined analyses. Besides pooling word frequency, a new factor of lexicality, with two levels: word versus pseudoword, was added. Then, mean reaction times and error data were both submitted to separate ANOVAs with first-SF (high vs. low), second-SF (high vs. low) and lexicality (word vs. pseudoword) as within-subjects but between-items factors.

The ANOVAs on latency data revealed a reliable main effect of lexicality [$F1$ (1, 38) = 181.15, $p < .001$; $F2$ (1, 120) = 118.33, $p < .001$]: words were responded to considerably faster than pseudowords. The first-SF was significant by subjects [$F1$ (1, 38) = 31.60, $p < .001$] and marginally by items [$F2$ (1, 120) = 3.74, p = .055] showing longer RTs for HF1 stimuli than for LF1 stimuli. Second-SF was also significant [$F1$ (1, 38) = 49.40, $p < .001$; $F2$ (1, 120) = 10.23, $p < .005$] revealing the same tendency: longer RTs for HF2 words and pseudowords than for LF2 words and pseudowords. Moreover, the interaction between lexicality and second-SF reached statistical significance in the subject analysis [$F1$ (1, 38) = 7.74, $p < .01$; $F2$ (1, 120) = 1.25]. The inhibitory effect of second-SF is quite bigger in pseudoword stimuli (33 ms) than in words (14 ms). No more effects were reliable in the RTs analyses.

The analysis of errors also showed that lexicality was reliable [$F1$ (1, 38) = 14.54, $p < .001$; $F2$ (1, 120)= 7.05, $p < .01$] with pseudowords producing more errors than words. Both syllable-frequency factors were significant: first-SF [$F1$ (1, 38) = 14.83 $p < .001$; $F2$ (1, 120) = 5.50, $p < .05$] and second-SF [$F1$ (1, 38) = 14.67, $p < .001$; $F2$ (1, 120)= 6.50, $p < .05$] with more errors were made on stimuli with high-frequency syllables with respect to stimuli having low-frequency syllables. Two interactions were significant in the analysis by subjects: lexicality x second-SF [$F1$ (1, 38) = 8.64, $p < .01$; $F2$ (1, 120)= 2.61] showing the same trend than in the RTs analysis, namely, there was a difference in errors between HF2 and LF2 pseudowords (6% vs. 3%, respectively) but not in words (the difference was 0.7%). The interaction between first-SF and second-SF was also reliable in the analysis by subjects [$F1$ (1, 38) = 5.71, $p < .05$; $F2$ (1, 120)= 2.28] with the bigger amount of errors (6%) located when both syllables are high frequency in comparison with the other three conditions (3%). No further effects yielded significance.

DISCUSSION

First of all, the results of this experiment have shown that the pattern of results for syllable frequency and word frequency obtained previously were successfully replicated here employing different stimuli [ii]. In the analyses over the word data, a robust word frequency effect was found, with high-frequency words being responded to faster than low-frequency words. Most models of word recognition incorporate this effect, via frequency-ordered search (Forster, 1976), via resting level of activation (e.g. McClelland & Rumelhart, 1981), or via weight among connections (e.g. Seidenberg & McClelland, 1989). But the main goal of this experiment was to dissociate the role of each syllable in the SF effect, both in disyllabic words and pseudowords. The word analyses showed an weak inhibitory effect of first-SF for low-frequency words but not for high-frequency words, although the interaction between word frequency and SF (for both the first and the second syllables) was not significant. This pattern, despite not significant, has been also obtained in previous analogous studies (Carreiras et al., 1993; Perea & Carreiras, 1998) and fits quite well with the activational model assumed: high-frequency words must be less affected by the number of syllabic neighbors activated (Carreiras et al., 1993) or by the number of higher frequency syllabic neighbors activated (Perea & Carreiras, 1998) than low-frequency words because their higher resting level of activation. Moreover, this result supports partially the Tousman and Inhoff's model, which predicts that syllabic effects would only appear in low frequency words.

It is also worthy of comment that a weak inhibitory effect of second-SF was obtained both in high and low-frequency words. However, the data of the conjoined analyses on words and pseudowords together have revealed that, whereas the inhibitory first-SF effect was shared by low-frequency words and pseudowords, the inhibitory second-SF effect was restricted to pseudowords. Previous studies suggesting that syllables play a role of activating lexical candidates during visual word recognition (Carreiras et al., 1993; de Vega et al. 1990) have not claimed anything about the particular role of syllables depending on their serial position in the word (or pseudoword). Other studies (Álvarez et al., in press; Domínguez et al., 1997; Perea & Carreiras, 1998) focused on the role of the first-SF finding the expected effects, although they did not test other syllables in the word. The results of the present experiment seem to support the idea that the first syllable is crucial in lexical access, having a role of activating word candidates. Moreover, the fact that first-SF effect has been obtained both for words and pseudowords in a lexical decision task seems to indicate that the effect cannot be attributed to purely lexical (e.g. word meaning activation) or postlexical levels, but to prelexical mechanisms operating at the interface between sublexical units and word nodes (e.g., activation of word nodes by syllabic units and/or competition among activated word nodes). Thus, an activation model incorporating a syllabic level can easily accommodate our results, as it has been suggested (Carreiras et al., 1993; de Vega & Carreiras, 1989; Perea & Carreiras, 1998; Rapp, 1992; Taft, 1991; Tousman & Inhoff, 1992). High-frequency syllables, in first position, would activate more syllabic neighbors (and more higher frequency syllabic neighbors) than low-frequency syllables, both in words and pseudowords, because the lexical decision task requires computing lexical information. The mutual inhibition among word nodes would explain the inhibitory effect of first-SF and the fact that this effect is bigger for low-frequency words (the competition of word nodes would not affect so much to high-frequency words because of their high resting levels of activation).

An important finding of this experiment was the clear inhibitory effect of second-SF in pseudowords. This result adds new restrictions to the proposed model. First, a totally-parallel model (e.g. McClelland & Rumelhart, 1981; Seidenberg & McClelland, 1989) cannot properly account for the present data because syllables play no role for such models. In the second place, the development of the PDP models has been restricted to monosyllabic words. Even incorporating a syllabic level (as it has been suggested by Grainger & Jacobs, 1994; Rapp, 1992, and Tousman & Inhoff, 1992) the problems to explain our data would remain: PDP proposals would predict the effects of both syllable frequencies also in words. Moreover, the fact that the effect of the second syllable is inhibitory in pseudowords seems to indicate that its role is not qualitatively different to the role of the first syllable. Thus, in principle, this result seems to support the notion of an activational-based model including sequential-like properties. In the case of words, if we assume that the first syllable plays a privileged role (because it is processed in the first place or because it has greater weights of connections with word nodes), when the second syllable is processed, one candidate will be quickly selected from the activated set by the first one. This second syllable only has to contribute to activate one candidate: the correct one (and that is why the effect of its frequency is weaker in words). However, in the case of pseudowords, when the second syllable is processed no candidate can be selected or can gain in activation (inhibiting the activation of its syllabic neighbors afterwards), and that is why its function of activating its own set of candidates emerges.

To summarize, the results partially support an activation-based model with sequential-like properties. This sequential-like character can be due to the assignation of greater weights to the connections between first syllable and word nodes than to the connections between second syllable and word representations (Grainger et al., 1992), or because there is an eye fixation bias toward the first part (grossly, the first syllable) of the word (e.g. Lima & Inhoff, 1985; Rayner, 1979) or because reading proceeds in a left-to-right fashion, even within a word. Moreover, a serial-search model (Forster, 1976; 1989; Taft & Forster, 1976) guided by an access code (the first syllable) would also explain perfectly the effect of first SF obtained both for words and pseudowords, but perhaps it would have some problems to explain the second-SF effect. The function of the last syllable would be to close the search when an entry matched the stimulus (or to decide nonword in the case of pseudowords), being that its frequency should facilitate or produce a null effect (although no prediction would be clearly made about this issue). However, despite of these results, more evidence would be necessary to conclude that there is a bias toward the first syllable or a sequential-type processing. This is the objective of the next experiments.

EXPERIMENT 2

The differential syllable-frequency effect of first and second syllable in disyllabic words and pseudowords in Experiment 1 fits several proposals that have assumed possible sequential-type mechanisms in visual word recognition. In particular, according to the model proposed by Taft and Forster (1976; Forster, 1976) and Tousman and Inhoff (1992), the first syllable would be the access code that guides the process of lexical search for multisyllabic words. The second syllable (in disyllabic words) would play no role and, in any case, its function would be qualitatively different to that of the first one. Parallel activation models also propose that the word-initial bias can take the form of initial letters providing greater activation of word nodes than final letters would (Grainger et al., 1992; Grainger & Jacobs, 1993). Although these authors originally did not make any claim about the role of sublexical units, in a more recent paper they have suggested that sublexical phonological codes (e.g. syllables) could receive activation from the letter level and send on activation to the word level (Ferrand et al., 1996; Grainger & Jacobs, 1994). However, the results of Experiment 1 are not conclusive, especially because the effects are not too strong. In order to test if there is some first-syllable bias, the current experiment used a temporal-separation technique, similar to that employed by Lima and Pollatsek (1983), Sánchez-Casas et al. (1991) and Taft (1987). This task uses a priming paradigm in a lexical decision task, in which the prime is a single syllable. In the present experiment, we included the priming condition as a new within-subject factor in the design. Subjects received the stimuli of Experiment 1 with either the first syllable or the second syllable of the stimulus as primes for 50 milliseconds, being followed by the complete stimulus. We predict that the pattern of results for SF will be substantially the same as in the previous experiment. Even more important, a clear advantage of first-syllable primes over second-syllable primes would obviously support the notion of a sequential-type processing.

Previous research using this technique have concluded that only with a lag of 200 ms a reliable pattern of results emerges (e.g., Sánchez-Casas et al., 1991; Taft, 1987). However, Lima and Pollatsek (1983) employed a prime-target delay of 90 ms, "based on pretesting which indicated that it was long enough to allow for a significant priming effect, but not so long that the prime would produce conscious guessing strategies" (p. 318). Grainger and Jacobs (1993) argued that the use of a prime-target delay of 90 ms is long enough to allow subjects to identify the primes and predict the whole word. Thus, they chose a prime duration of 57 ms, obtaining reliable results. According to Forster (1993), using a very brief SOA (50-60 ms) prevents subjects to have any conscious awareness of the prime. Because target interrupts the processing of the prime, the priming stimulus is perceptually processed but it is not encoded into episodic memory and subjects are unable to report it. In order to discard an interpretation of our data on the basis of guessing strategies, primes of 50 ms of duration were used in Experiment 2. This interval is long enough to obtain priming effects (and maybe for lexical candidates being activated) but it is short enough to avoid strategic processes.

According to totally-paralel models (e.g. McClelland & Rumelhart, 1981; Seindenberg & McClelland, 1989), syllables play no role and there is no sequential mechanism. Thus, both primes (first or second syllables) must produce similar results (no advantage of any syllable is expected). However, according to serial-search model in which the first syllable forms the access code (e.g. Taft & Forster, 1976), there must be an advantage when presenting the first syllable as a prime of the whole stimulus in comparison with presenting the second one. A priming of the first syllable would allow the processor to select the correct "bin" (the lexical candidates which share that first syllable). Thus, presenting the first syllable previously, the segmentation and the isolation of the access code will be facilitated. Moreover, a lack of an inhibitory effect of second-SF, both in words and pseudowords, would be an additional support for this model. According to activation-based models with sequential-like properties (e.g. Grainger et al., 1992), all syllables in multisyllabic stimuli would have the same role of activating lexical candidates. The bias toward initial syllables compared with final syllables would be quantitative (e.g. via greater weights of connections between first syllable-word nodes than between second syllable-word nodes, via eye fixations or just because the first syllable is processed before). This hypothesis would also predict an advantage of the presentation of the first syllable over the presentation of the second one. In adition, the syllable-frequency effects obtained in Experiment 1 should arise here, supporting our notion of syllable as activational unit of word nodes. Specifically, we might expect an inhibitory effect of first-SF, and an inhibitory effect of second-SF but only in pseudowords.

METHOD

Participants. Twenty-seven undergraduate students from the University of La Laguna who received course credits for their participation. None of them participated in Experiment 1.

Material and design. The same set of stimuli used in Experiment 1 (64 words and 64 pseudowords) were employed here. In this case the design was a 2x2x2x2 repeated-measures design. Three of the factors were the same as in previous experiments: 1) Lexicality (word vs. pseudoword), 2) First-SF (high vs. low), and 3) Second-SF (high vs. low). The fourth factor was the type of prime, with two conditions: priming of the first syllable and priming of the second syllable, as a within-subjects factor: subjects received half of the stimuli with a previous presentation of the first syllable and the other half with a previous presentation of the second syllable.

Procedure. The Temporal Separation Technique was employed (see Lima & Pollatsek, 1983; Sánchez-Casas et al., 1991; Taft, 1987). Participants were tested individually and were instructed to classify the visually presented items as words or nonwords exactly as in Experiment 1. Half of the stimuli of each condition (four stimuli) were presented with a priming of the first syllable, and the other half with a priming of the second syllable. Each trial started by presenting a row of asterisks (one per each letter of the stimulus) for 1500 ms in the same location where the stimulus would appear later. Then, in the first-syllable priming condition, the first syllable of the stimulus was presented for 50 ms (in the same location that would appear in the whole stimulus) immediately followed by the entire stimulus. In the second-syllable priming condition, the procedure was the same but the second-syllable was presented as a prime for 50 ms, also in the same location that would appear in the word or pseudoword. Two lists of stimuli were used so that every stimulus could appear in each of two prime conditions (first or second syllable) and each list was assigned to one of two groups of subjects. There were 20 practice trials and the presentation of the experimental items and also the type of prime were randomized for each subject. Subjects were not informed about the two types of primes.

RESULTS

A cut-off of 300-1500 ms was used, eliminating a 2.1% of the data, as well as the incorrect responses. Mean RTs and errors rates were submitted to separate 2x2x2x2 ANOVAs including lexicality (word vs. pseudoword), first-SF (high vs. low), second-SF (high vs. low) as within-subjects but between-items factors, and type of prime (first vs. second) as within-subjects and within-items factor. Table 2 displays mean reaction times and error rates.

Table 2. Mean reaction times (in ms) and percentage of errors (in parentheses) as a function of lexicality (words vs. pseudowords), syllable frequency (1^{st} & 2^{nd} syllables) and type of priming (first vs. second syllables) in Experiment 2.

	Syllable frequency (1^{st} & 2^{nd})			
	1^{st} High		**1^{st} Low**	
Priming 1^{st} syll.	2^{nd} High	2^{nd} Low	2^{nd} High	2^{nd} Low
Words	657 (5.5)	646 (2.7)	631 (2.3)	631 (1.4)
Pseudowords	748 (6.9)	721 (2.3)	741 (6.5)	714 (2.7)
Priming 2^{nd} syll.				
Words	668 (3.7)	675 (2.7)	645 (2.3)	649 (1.4)
Pseudowords	772 (2.7)	724 (1.4)	746 (4.2)	715 (1.8)

Latency analyses revealed that all the main effects were significant: lexicality [$F1$ (1, 26)= 112.78, $p < .001$; $F2$ (1, 120) = 107.07, $p < .001$] words producing faster RTs than pseudowords; first-SF [$F1$ (1, 26) = 19.04, $p < .001$; $F2$ (1, 120) = 3.97, $p < .05$] HF1 stimuli producing slower RTs than LF1 stimuli; second-SF, by subjects [$F1$ (1, 26) = 14.75, $p < .001$] and marginally by items [F2 (1, 120) = 3.88, p = .051] with HF2 words/pseudowords producing slower RTs than LF2 words/pseudowords) and also the type of prime [$F1$ (1, 26) = 12.29, $p < .005$; $F2$ (1, 120) = 6.25, $p < .05$] with longer RTs for priming of the second syllable than for priming of the first one. As expected, there was a significant interaction between lexicality and second-SF, by subjects [$F1$ (1, 26) = 13.54, $p < .001$] and marginally by items [$F2$ (1, 120) = 3.49, $p = .064$]. The interaction was caused by the fact that the difference between words with high-frequency second syllable and low-frequency second syllable is 0 ms whereas there is a difference of 34 ms in the case of pseudowords. The remainder effects did not reach significance.

The analyses of variance on the error rate showed a significant main effect of the second-SF [$F1$ (1, 26) = 14.71, $p < .001$; $F2$ (1, 120) = 5.28, $p < .05$] with more errors observed in stimuli with high-frequency second syllable, and first-SF, only in the by-items analysis [$F1$ (1, 26)= 1.60; $F2$ (1, 120) = 11.64, $p < .001$] with more errors for HF1 stimuli. No other effects were reliable.

DISCUSSION

The main results of SF in the previous experiment were successfully replicated here, in spite of the reduction in the number of stimuli per cell as a consequence of the introduction of the new factor type of prime. First-SF produced an inhibitory effect both on words and pseudowords. With respect to the second-SF, the results are clearer than in Experiment 1: The inhibitory influence of second-SF was restricted to pseudowords whereas, in words, tends to be facilitatory when the first syllable was of low frequency (see Table 2). However, and more importantly, there was an advantage in presenting the first syllable as a prime in comparison with presenting the second one. This result, together with the clear first-SF effect and the lack of second-SF effect in words, agrees again with a sequential-type processing or a bias toward the first syllable. A totally-parallel model that proposes a parallel processing of different parts in a word (e.g. Jared & Seindenberg, 1990; Seidenberg & McClelland, 1989), or with two syllables having the same role, cannot be supported by the present data (the frequency of both the first and the second syllable should have been equally relevant in words and no advantage at all would have been expected for presenting the first syllable as a prime over presenting the second one).

In contrast, models which assume that the first syllable is the main access unit to the mental lexicon (Forster, 1976; Taft & Forster, 1976; Tousman & Inhoff, 1992) are partially supported by the present data. These models would predict that a first-syllable prime (the access code) would facilitate the processing of words because the presentation of the access code allows the processor to select the correct bin and subsequently the correct entry (Tousman & Inhoff, 1992). The advantage of the first-syllable prime over the second one seems to support this point of view. It is less clear, however, how these models can explain the complex pattern of second-SF in words and pseudowords we have obtained.

On their side, activation-based models with a sequential character (as suggested by Grainger et al., 1992) can easily accommodate the results obtained in this experiment. Both syllables could share the function of activating word nodes, as it has been proposed in several studies (Carreiras et al., 1993; de Vega et al. 1990; Domínguez et al., 1993; 1997; Perea & Carreiras, 1998) but there is a bias toward the first one. The inhibitory influence of first-SF is explained by the lateral competition of syllabic neighbors activated (more specifically, because the frequencies of these candidates, low-frequency words being more affected than high-frequency words). Whereas the role of the first syllable is shared both for words and pseudowords (suggesting that the effect is not purely lexical or postlexical), the effect of the second syllable only takes place when the stimuli are not in the mental lexicon. In other words, the activation of the second-syllable candidates only seems to occur when none first-syllable candidate was selected (e.g. overactivated). The nature of this sequential-type mechanism can be of different sources: temporal (for instance, if the first syllable is processed before via eye fixation, as several studies have concluded), functional (assigning greater weight to the connections between first syllable and word level than to the connections between second syllable and the same word representations), etc.

EXPERIMENT 3

Experiments 1 and 2 showed a pattern of results consistent with respect to previous findings on syllable-frequency effect. But we obtained an important qualification of the effect: we have got evidence of a sequential-like processing, with a bias toward the first syllable (see priming effect in Experiment 2). Additionally, even when both syllables have a role in activating lexical candidates, the effect of the second syllable appears only in pseudowords, where no candidates (activated by the first one) can be recognized.

The present experiment uses a different set of materials more representative of the Spanish lexicon. The aim of these improve materials was to confirm and generalize the previous findings. The experiment follows the same logic in the former one and employing essentially the same methodology, and it is an attempt to make clearer the syllable-frequency effect and its sequential character, excluding the possibility for other factors to make a confounding with the syllable-frequency effects. These are the main improvements in the materials.

First, the choice of the stimuli in Experiments 1 and 2 was seriously restricted by the frequency dictionaries employed. For some cells, the eight words per condition were almost the exhaustive list. It is obvious that this issue could be a problem if our intention is to obtain data that are typical of Spanish lexical access processes. The syllable-frequency dictionary by Álvarez et al. (1992) was extracted from a 30,000-words sample. Its functionality has been proved but its limitations to get stimuli are also evident. We selected for this experiment a new set of stimuli from another Spanish data base of two-million words: the one by Alameda & Cuetos (1995). This allowed us to select more and different stimuli, which are not the only ones for each condition. Moreover, we decide to choose low-frequency words because, as we have seen, the syllable-frequency effect arises in this kind of words.

Second, the whole set of words previously used had first-syllable stress: could this feature explain the bias toward first-syllable? In fact, there is some evidence that strong syllables could act as access code, at least in spoken word recognition (e.g. Grosjean & Gee, 1987). The new set of disyllabic stimuli included both words with first-syllable stress and words with second-syllable stress in order to discard an explanation in terms of stress pattern.

Third, some experiments in speech perception (Sebastián-Gallés, Dupoux, Seguí & Mehler, 1992) have found that task demands play an important role in the presence or absence of syllabification. Half of the words (and syllables) in our experiments 1 and 2 were high frequency and half were low frequency. Could this partial and extreme experimental context influence in the pattern of data ? To avoid this possibility, we used a set of filler words with a range of SF in the middle of the interval between high and low syllable-frequency, and with a word frequency above the interval used in the experimental words.

From a theoretical point of view, previous research assumed that the number of syllabic neighbors explained the syllable-frequency effect (e.g. Carreiras et al., 1993). However, subsequent studies demonstrated that the number of higher-frequency syllabic neighbors was accounting for the effect (Perea & Carreiras, 1998), also based on the notion of competition. In this experiment, the number of higher-frequency syllabic neighbors were calculated for each word in order to certify that this factor underlies our syllable-frequency manipulations. This values were submitted to a regression analysis over RTs with other predictors that could be related to SF, such as bigram frequency and orthographic neighborhood values, with the objective of testing the main influence of having higher-frequency syllabic neighbors on RTs. Additionally, we have added a new control priming condition (a neutral prime) in order to analyse either the facilitatory or inhibitory effects of syllabic priming.

METHOD

Participants. Thirty-five Psychology undergraduate students of the University of La Laguna participated in this experiment in order to receive course credits. None of them participated in the previous experiments.

Material and design. A new set of stimuli were used for this experiment. A total of 40 low-frequency words (the frequency of occurrence was from 1 to 40, mean, 12, and SD, 13), four or five letters long, were selected from the Dictionary of Frequency of the Spanish Linguistic Units, a data base of two-million words (Alameda & Cuetos, 1995), by combining two factors: First-SF (high vs. low) and second-SF (high vs. low). Syllables were selected according to their token frequency in the Dictionary of Frequency of Spanish Syllables (Cobos et al., 1995), a dictionary from the data base previously mentioned. Syllables were considered of high frequency when they had a minimum frequency of occurrence of 3500 per million, and low frequency when they had a maximum frequency of 100 per million. Although SF *per se* was the initial manipulation in words (and pseudowords), in this experiment we also calculated the number of higher-frequency syllabic neighbors (from both the first and the second syllable) of the words, in order to be sure that there were real differences in these factors among conditions. The characteristics of the selected words are presented in Table 3. Moreover, for each condition, seven of the words had the stress on the second syllable and three words had the stress on the first-syllable. Words were matched across condition for length.

Forty disyllabic orthographically legal pseudowords were also constructed and matched across conditions for length and bigram frequency by combining the same two factors: First-SF (high vs. low) and second-SF (high vs. low), using the same limit values than in words. These pseudowords were also matched for length with words. Thus, the whole design was a 2x2x2x3, with 1) Lexicality (word vs. pseudoword), 2) First-SF (high vs. low), 3) Second-SF (high vs. low) and 4) type of prime, with three levels: priming of the first syllable, priming of the second syllable and a control condition (e.g., for the word "mesa" the prime was "----"). This factor was also within-items: each word/pseudoword was presented three times to each subject preceded by the three different prime conditions. In addition, a set of filler stimuli were included: 36 disyllabic words and 36 disyllabic pseudowords. These stimuli had SF means located in the middle of the interval used for the experimental items: first syllable-frequency (mean, 931 and SD, 318, both for words and pseudowords), second-SF (mean, 1075 and SD, 396, also both for words and pseudowords). The word frequency was higher than the experimental words (mean, 71, and SD, 56). Each subject received three blocks of stimuli, with each stimulus appearing with a different prime across blocks. Both, the order of presentation of blocks and the stimuli presentation within each block were randomized.

Table 3. Characteristics of words used in Experiment 3.

Word class	MeanWF	HF+1	HF+2	MeanBig.Fr.
Hi1st - Hi2nd	11 (14)	44 (23)	40 (16)	3801 (4361)
Hi1st - Lo2nd	13 (9)	31 (13)	2 (1.6)	3914 (1539)
Lo1st - Hi2nd	14 (16)	3 (3)	68 (37)	2655 (2042)
Lo1st - Lo2nd	10 (10)	2 (1.5)	2 (1.1)	842 (897)

Note: Means and Standard Deviations (in parentheses) are displayed in the table. Word class is the type of word according its syllable frequency (high, Hi, and low, Lo) for both the first-syllable (1st) and for the second one(2nd). MeanWF is the mean frequency of words based on a count of 2,000,000 Spanish words (Alameda & Cuetos, 1995). HF+1 and HF+2 are the average number of higher frequency syllabic neighbors of the first syllable and the second syllable MeanBig.Fr. is the mean frequency of the bigrams (pairs of letter) within a word (the four variables were calculated from Alameda & Cuetos, 1995).

Procedure. The same procedure than in Experiment 3 was employed here, with the differences commented in Material.

RESULTS

A cut-off of 300-1500 ms was used, eliminating a 2 % of the data, as well as the incorrect responses. Separate 2x2x2x3 ANOVAs were carried out, with lexicality, first-SF, second-SF as within-subjects but between-items, and type of prime as within-subjects and within-items factors, both over mean reaction times and over the error rates.

The distractor set of items was not included in the analyses. Table 4 displays mean reaction times and error rates.

ANOVAS on RTs showed the following significant main effects: lexicality [$F1$(1, 34)= 93.18, $p < .001$; $F2$ (1, 72) = 113.79, $p < .001$] words producing faster RTs than pseudowords, first-SF [$F1$ (1, 34) = 72.23, $p < .001$; $F2$ (1, 72) = 7.20, $p < .005$] HF1 words/pseudowords producing slower RTs than LF1 words/pseudowords, and type of prime [$F1$ (2, 68) = 6.62, $p < .005$; $F2$ (2, 144) = 11.66, $p < .001$] showing that the first-syllable priming condition produced a 11 ms-facilitation in comparison with the control condition (SNK, p<.001) whereas second-syllable priming condition inhibited recognition latencies in 8 ms also compared with the control priming condition (SNK, $p < .005$). The effect of the second-SF was significant only by subjects [$F1$ (1, 34) = 13.77, $p <$ .005; F2 (1, 72) = 1.70] also with longer RTs for words with high-frequency second-syllable.

Table 4. Mean reaction times (in ms) and percentage of errors (in parentheses) as a function of lexicality (words vs. pseudowords), first-syllable frequency (high vs. low), second-syllable frequency (high vs. low) and type of prime (first syllable vs. second syllable vs. control condition) in Experiment 3.

	Syllable frequency (1st & 2nd)			
	1st High		1st Low	
Priming 1st syll.	2nd High	2nd Low	2nd High	2nd Low
Words	701 (2.6)	696 (2.8)	653 (1.4)	674 (1.7)
Pseudowords	786 (2)	757 (3.1)	766 (1.7)	730 (0.3)

Priming 2nd syll.				
Words	702 (4)	693 (2.3)	686 (0.9)	705 (2.8)
Pseudowords	787 (2.6)	798 (0.6)	799 (1.7)	745 (2.3)
Control condition				
Words	693 (2.6)	691 (0.6)	656 (1.7)	673 (2.3)
Pseudowords	806 (4.8)	784 (3.1)	796 (1.7)	753 (0.3)

Concerning the interactions, lexicality x second-SF was significant [*F1* (1, 34) = 44.12, $p < .001$] and marginally by items [*F2* (1, 72) = 3.76, $p = .057$]. Post-hoc comparisons indicated that HF2 words produced slightly shorter RTs than LF2 words (a non-significant difference of 6 ms), whereas the opposite pattern ocurred in pseudowords: HF2 pseudowords produced longer RTs than LF2 pseudowords (a difference of 25 ms, SNK, $p < .001$).

The interaction lexicality x type of prime was also significant [*F1* (2, 68) = 6.10, $p < .005$; *F2* (2, 144) = 6.15, $p < .005$] showing an inhibitory priming effect of the second-syllable acting as a prime compared with the control priming condition in words but not in pseudowords (SNK, $p < .001$), whereas a facilitatory priming effect of the first-syllable prime compared both with the second-syllable prime and the control condition was significant in pseudowords. However, it is important to mention that the difference between first-syllable priming condition and second-syllable priming condition was obtained both in words and pseudowords (SNK, $p < .001$). The interaction lexicality x first-SF x second-SF yielded significance in the by-subjects analysis [*F1* (1, 34) = 17.25, $p < .001$] and marginally by items [*F2* (1, 72) = 3.02, $p < .1$] showing a facilitatory effect of second-SF only in those words with low-frequency first syllable (no difference was found for second-SF in words with high-frequency first syllable). In contrast, in pseudowords both first and second-syllable frequencies produced significant inhibitory effects (SNK, $p < .005$). No other effects were significant.

The analyses of variance on error rate showed a significant main effect of first-SF [*F1* (1, 34) = 23.97, $p < .001$; *F2* (1, 72) = 6.04, $p < .05$] more errors observed in stimuli with high-frequency first syllable, and two significant interactions: prime x lexicality x first-SF [*F1* (2, 68) = 3.38, $p < .05$; *F2* (2, 144) = 3.20, $p < .05$], and lexicality x first-SF x second-syllable, only in the by-subjects analysis [*F1* (1, 34) = 5.27, $p < .05$]. However, there was no particular result to remark. No other effects were reliable.

DISCUSSION

The pattern of data obtained in Experiment 2 was replicated here: an inhibitory effect of first-SF (both in words and pseudowords), an inhibitory effect of second-SF only in pseudowords (this factor tended to be facilitatory in words, specially when the first syllable was low frequency) and a superiority of the priming of the first syllable over the priming of the second one. The introduction of a baseline condition for the priming effect showed that second-syllable prime inhibited RTs in words. We know that there is a bias toward the first one, and it is likely that the second-syllable acting as a prime produced an activation of word nodes (which share that syllable but in first position, as it happens when the first syllable is presented). In such case, the competition activity (among nodes activated by the prime and nodes activated by the first syllable in order to recognize the word) must be huge and could explain the inhibition observed. Nevertheless, the advantage of the priming of the first syllable over the priming of the second one (obtained in Experiment 2) remained here, for both words and pseudowords.

An important contribution of this experiment is that the critical results were obtained: 1) with a different set of stimuli, 2) with words stressed in the second syllable, and 3) including a set of filler stimuli with middle SF mixed with the experimental material.

However, there are still some factors not entirely controlled in our materials. First, bigram frequency was not controlled in our word stimuli in none of our experiments (except in the pseudowords of Experiment 3). Consequently, it is possible that, at least part of the syllable-frequency effect could be attenuated by this factor, although Carreiras et al. (1993) and Rapp (1992) have found reliable syllabic effects when controlling for orthographic redundancy. Secondly, neighborhood density and neighborhood frequency can also be confound with syllable-frequency: the experiments did not provide any information concerning whether the SF effect arises from the number of orthographic neighbors, their frequency, or both, although Perea & Carreiras (1998) have demonstrated that these orthographic factors cannot account for syllable-frequency effect. For that reason, we carried out a regression analysis as a post hoc control including five predictors: number of higher frequency syllabic neighbors of the first syllable (words that share the first syllable being of higher frequency than the stimuli), number of higher frequency syllabic neighbors of the second syllable, positional bigram frequency -calculated from Cobos et al. (1995)'s dictionary of bigram frequency in Spanish-, number of orthographic neighbors (neighborhood size) defined as Coltheart´s N (Coltheart, Davelaar, Jonasson & Besner, 1977-) and number of higher frequency orthographic neighbors (neighborhood frequency, see

Grainger, 1990). The regression was conducted on items' word latencies of the Experiments 2 and 3 together, collapsing the different prime conditions. As expected, the regression analysis showed that the only significant effect was the number of higher frequency syllabic neighbors of the first syllable [T (1, 98)= 3.96, $p < .001$]. The factor responsible for the inhibitory SF effect in words appears to be the number of higher frequency syllabic neighbors of the first syllable rather than the number of syllabic neighbors (see Table 5).

Table 5. Pearson and partial correlations between reaction times and four predictors in Experiment 2 & 3.

	Pearson	Partial
Hi. freq. syll. neig. 1st syll.	.484	.372 **
Hi. freq. syll. neig. 2nd syll.	.162	.135
Neighborhood size	-.032	-.117
Neighborhood frequency	.324	.013
Bigram frequency	.025	-.061

Note: Hi. freq. syll. neig. 1st syll. refers to the number of higher frequency syllabic neighbors (words that share the first syllable). Hi. freq. syll. neig. 2st syll. is the same for the second syllable. Bigram frequency is the mean frequency of the bigrams within a word.** $p < .001$.

The results of this regression agreed totally with results obtained previously (Perea & Carreiras, 1998) and confirmed that the syllable-frequency effect is better explained by the number of higher frequency words which share the first syllable. Additionally, they showed that the effect cannot be accounted by other orthographic variables neither the bigram frequency nor orthographic neighborhood factors can account for he syllable-frequency effect (see also Perea & Carreiras, 1998).

GENERAL DISCUSSION

The results of our experiments converge with previous observations about the role of syllables in visual word recognition in Spanish. In addition, they are also fully compatible with different theoretical frameworks and results obtained in other languages. For instance, Ferrand et al. (1996) explained the inhibitory effect of SF (as a comment about Carreiras et al., 1993 data) at the level of sublexical input phonology, assuming that this level is syllabically organized. The syllabic units would send activation to word nodes and the lexical inhibition process would explain the SF effect. The similarity of this explanation with our proposal is notorious. More specifically, the experiments reported here replicated the inhibitory effects of SF supporting the notion of syllables as activational units of word candidates (e.g. Carreiras et al., 1993; Perea & Carreiras, 1998). Moreover, our data have shown that this effect arises not only in low-frequency words but also in pseudowords, suggesting that the effect is neither purely lexical or postlexical but located in the process of lexical access.

Nonetheless, this research was mainly designed to explore in more detail some mechanisms underlying the syllable-based activation model we have assumed for word identification in Spanish. Despite the amount of studies on syllable-frequency effect in this language (Carreiras et al., 1993; de Vega et al. 1990; de Vega & Carreiras, 1989; Domínguez et al., 1993; 1997; Perea & Carreiras, 1998), none of them specifies the role of the particular syllable position within a word or a pseudoword (but see Álvarez et al., 1998). Some of these studies assumed that the first syllable is the important one, focusing on the manipulation of the frequency of that unit (e.g. Perea & Carreiras, 1998), while others dealt with the mean frequency of the syllables in a stimulus (e.g. Carreiras et al., 1993). In the syllable-based activational model syllables would send activation to word nodes. For instance, Carreiras and colleagues suggested that the initial cohort activated by a given stimulus is composed by syllabic neighbors. Syllabic neighbors were defined as words that share a syllable in the same position with the target but the authors did not explicitly mention which syllable. Thus, words with high-frequency syllables will activate a larger set of word candidates (including candidates of higher frequency, as demonstrated by Perea & Carreiras, 1998) than words with low-frequency syllables. It will take longer to select a word with higher-frequency neighbors than a word with no higher-frequency neighbors, and this could explain why the syllable-frequency effect is inhibitory. The experiments reported here go one step further trying to analyze whether the two syllables of disyllabic words play the same or different role in word recognition.

We manipulated the first-SF and the second-SF both in disyllabic words and pseudowords. Experiment 1, using a lexical decision task, revealed a standard first-SF effect both for low-frequency words and pseudowords and a second-SF effect only in pseudowords. Experiment 2 used a priming paradigm in which either the first or the second syllable acted as primes of the whole stimuli and virtually the same pattern of results was obtained: an inhibitory first-SF in words (much stronger in low-frequency words) and pseudowords, an inhibitory second-SF only in pseudowords, and a facilitatory tendency of second-SF in words with low-frequency first syllable. Moreover, an advantage of the first-syllable prime over the second-syllable prime was found (priming of the first syllable producing shorter RTs than priming of the second one). Experiment 3 allowed us to conclude that the effects obtained in Experiments 1 and 2 are reproducible with other materials and cannot be attributed to other confounding factors, such as task demands, stress position or purely orthographic variables (e.g., bigram frequency, orthographic neighborhood size or orthographic neighborhood frequency). Additionally, the use of a control priming condition showed that the second syllable produced an inhibitory effect in words.

In general, models in visual word recognition differ in the degree in which they assume that different parts within a word are processed in different ways. For instance, for the interactive activation model (McClelland & Rumelhart, 1981), for the PDP model (Seidenberg & McClelland, 1989) and for the activation-verification model (Paap et al., 1982), all letters in a given word participate simultaneously in the activation of word representations (or word nodes). For these models, individual syllables (and any further sublexical units) play no role in the process of word recognition. However, the development of these proposals has been restricted to monosyllables. Little research has been carried out in order to study the processing of multisyllabic words (Tousman & Inhoff, 1992), and the difficulty to extend these models to these stimuli has been pointed out by some authors (e.g. Seidenberg, Plaut, Petersen, McClelland & McRae, 1994). This difficulty is a drawback because multisyllabic words are very frequent in languages such as Spanish, where the average word length is more than 8 letters per word and the percentage of monosyllabic words is less than 8% (Perea & Carreiras, 1998). In addition, Carreiras et al. (1993) demonstrated that letter-cluster frequencies cannot explain by themselves the syllable-frequency effects. According to this and other empirical evidences, some authors have suggested that these models should be modified to incorporate syllabic representations (Ferrand et al., 1996; Grainger & Jacobs, 1994; Perea & Carreiras, 1998; Rapp, 1992;). Nevertheless, even assuming that modification, a totally-parallel model without sequential properties cannot adequately account for our results. Although both syllables of our stimuli seem to have the role of activating lexical candidates (a partial support for these models), we have obtained an effect of second syllable only on pseudowords. If both syllables had exactly the same weight (as predicted by a parallel model) both syllable frequencies would have had a similar influence, at least on words. It is important to remark that there was a tendency for second-SF to produce an opposite effect in words: a facilitation (Experiments 2 & 3). Besides, these two experiments showed an advantage of presenting the first syllable as a prime over presenting the second one. This result is an additional and evident support for the assumption of a sequential-type processing.

Furthermore, strictly-serial process models (e.g. Forster, 1976; Taft, 1979) assume that there is sequentiality in word processing, resulting in a superiority for word beginning over word ending. For instance, Taft and Forster (1976; see also Taft, 1979; 1986) proposed that visual word recognition proceeds in a left-to-right fashion. The unit which allows a sensory-lexical match is called the access code and corresponds to the first syllable of a word (in the case of multisyllabic words). These proposals claim that word beginnings (more specifically, the first syllable) play a privileged role in visual word recognition (see also Lima & Pollatsek, 1983; Tousman & Inhoff, 1992). Some of our findings partially support these proposals. The inhibitory effect of first-SF seems to be consistent with a model that proposes syllable as access unit (Forster, 1976). The bin selected by a high-frequency first-syllable will be bigger than the bin selected by a low-frequency one, or it is more likely to find a higher frequency word in the bin. Thus, the serial search will take longer in the first case (because the selection process takes longer) than in the second one. Moreover, the advantage of first-syllable prime over second-syllable prime, specially in words, would be predicted by these sort of models (Tousman & Inhoff, 1992). The first syllable is the most prominent part in a word (the access unit) and its prior presentation should be highly facilitatory, specially in words, where the access can be easily reached. This prediction has been partially confirmed: the first syllable is a better prime than the second one (Exp. 2 and 3). However, when a base line is used (Exp. 3) no facilitatory effect of the first-syllable prime was found in words (although first-syllable prime showed a superiority over second-syllable prime). Likewise, the inhibitory second-SF effect in pseudowords does not fit this proposal entirely, because in a serial model the access code would be constrained to the first syllable. In principle, there is no theoretical reason to expect an inhibitory effect of second-SF, a unit which closes the search by selecting a first-syllable lexical candidate but does not have any function of activating itself a searching space in the lexicon. Its effect should be facilitatory or null. To conclude, our data partially supported a serial-search model guided by the first syllable although not completely.

In contrast, several authors have claimed that activational-based models must include sequential-like properties, for instance via “assigning greater weights to the connections between initial letters and word representations than to the connections between end letters and the same representations” (Grainger et al., 1992, p.55), as suggested by empirical evidence about bias toward the initial part of a word. For such a proposal, it is not necessary to postulate totally-different roles between word beginnings and word endings, as serial-search models do, but just a quantitative difference. Several works have supported this claim, finding word-initial advantage in partial-word priming experiments (Grainger & Jacobs, 1993; Inhoff & Tousman, 1990). Convergent evidence has been found with eye movements techniques, revealing a bias toward initial letters (e.g. Briihl & Inhoff, 1995; Lima & Inhoff, 1985; O'Regan & Jacobs, 1992; Rayner, 1979; Rayner, et al., 1982). Although some of the activation-based proposals have not explicitly mentioned that syllables play any specific role, other authors have argued that phonological representations, such as syllables, can be implemented in these models between letter level and word level (e.g. Carreiras, Grainger & Perea, 1999; Ferrand et al., 1996; Grainger & Jacobs, 1994; Rapp, 1992; Taft, 1991). An activational model with sequential characteristics and including a syllabic level of processing can accommodate our results quite well. According to such a model the two syllables in disyllabic stimuli do not play totally-different roles. The difference between both syllables would be quantitative or temporal, with a bias toward the first one. When a disyllabic stimulus is presented, a cohort of word candidates that share one syllable with the stimulus is activated (at least in tasks which require computing lexical information). In other words, both syllables will activate a set of word nodes. Stimuli with high-frequency syllables activate larger cohorts including competitors of higher frequency than stimuli with low-frequency syllables. Consequently, the inhibition process (or the competition among candidates) is harder in the former case than in the latter and, obviously, high-frequency words will be much more affected by this competition than low-frequency words. However, the bias (temporal or functional) toward the initial syllable would give the process sequential properties. When the stimulus is a word, the activation of the candidates by the second one is not evident because one of the candidates, already activated by the first one, will soon gain in activation when the second syllable is processed. The activation of the second-syllable own lexical candidates is truncated, and its main contribution is reinforcing the activation of the correct candidate, being that its frequency could even facilitate instead of inhibit, specially when very few candidates are fighting (a tendency observed in Experiments 2 & 3 for words with low-frequency first-syllable). However, when the stimulus is a pseudoword, none of the candidates initially activated by the first syllable can be selected, so the mechanism of activation/competition of the second syllable is reflected on performance: the inhibition of both syllabic cohorts (activated by the first and by the second syllable) must be exhaustive. A model like this one explains perfectly our data: the inhibitory effect of the first-SF both in words and pseudowords, the inhibitory effect of second-SF only in pseudowords, the superiority of first-syllable priming, and the fact that syllable-frequency effect is restricted to low-frequency words (much more affected by the competition and with more syllabic neighbors of higher frequency).

Several arguments have been proposed in order to explain the specific source of this sequential mechanism or bias toward the first syllable. One possible source is the fact that most words are first learned in its spoken forms, where the processing is necessarily left-to-right, imposed by the sensorial modality (Grainger et al., 1992). Another possible explanation is that visual word recognition also proceeds in a left-to-right fashion although this sequentiality does not necessarily have to be temporal (e.g. Taft, 1979; 1986). Preferential eye-fixation toward initial part of words has also been argued to explain this bias (e.g. O'Regan et al., 1984; Briihl & Inhoff, 1995). The present paper does not provide a test on the nature of the syllabic bias, therefore, this issue must be examined in future experiments.

To sum up, this study has confirmed and extended previous findings about the role of syllable in visual word recognition in Spanish. Syllable seems to be a very important processing unit which activates lexical candidates, and this process has a sequential character, with a bias toward initial syllables. However, if syllabic effects are phonological, e.g. via phonological coding of the visual input, as suggested by Ferrand and colleagues (see an explanation of the results obtained by Carreiras et al., 1993 in Ferrand et al., 1996), or just orthographic (there is no difference between phonologic and orthographic syllable in Spanish), and if reading words in other languages with clear syllabic boundaries (e.g. Italian, French, Portuguese, etc.) involve the use of syllable as sublexical units, are questions that urge to be answered in further investigations.

RESUMEN

El efecto de frecuencia silábica se examinó en tres experimentos sobre lectura de palabras en español. Se emplearon palabras y pseudopalabras de dos sílabas en las que se manipuló la frecuencia posicional tanto de la primera como de la segunda sílabas, además de la frecuencia léxica (sólo en palabras). Se usó una tarea de decisión léxica (Experimento 1) y la técnica de segmentación temporal (Experimentos 2 y 3), en la que tanto la primera como la segunda sílaba actuaron como *primes* del estímulo completo, registrándose tiempos de reacción y errores. Los resultados reprodujeron el efecto inhibitorio de la frecuencia silábica obtenido en estudios previos y apoyan un modelo activacional con un nivel silábico de procesamiento. Sin embargo este modelo debe incorporar propiedades secuenciales: aunque ambas sílabas activan representaciones léxicas existe un sesgo hacia la primera. Se discuten las implicaciones de los resultados en relación con la noción de procesamiento secuencial.

Palabras clave: reconocimiento visual de palabras, acceso léxico, frecuencia de sílabas

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Notes

[i]We will call "inhibitory" effects to those results where frequency tends to get longer the RTs (in other words, high frequency producing longer Rts than low frequency), although we recognize that this effect cannot properly be called inhibitory without a baseline of comparison in a strict sense.

[ii]In order to examine if the present results replicate those of previous lexical decision experiments (e.g. Carreiras et al., 1993; de Vega & Carreiras, 1989), we carried out a new data analysis employing only a subset of our stimuli: words and pseudowords with both syllables being high or low frequency. Thus, the design for words was reduced to a 2x2 repeated-measures design (word frequency: high vs. low, and syllable frequency: high vs. low). In the case of pseudowords, only one factor was manipulated: syllable frequency (high vs. low). We will only comment the Rts results.

In the ANOVA on the RTs for **words** significant main effects of both factors were observed: word frequency, $F1\ (1, 38) = 25.27$, $p < .001$; $F2\ (1, 28) = 4.30$, $p < .05$, (longer RTs for low-frequency words), and syllable frequency, by subjects, $F1\ (1, 38) = 13.46$, $p < .001$, and marginally by items, $F2\ (1, 28) = 3.49$, $p = .072$, with words of low-syllable frequency being responded to more rapidly than those of high-syllable frequency. The interaction did not reach significance and the analysis on the error rate mirrored the Rts results. The only factor (syllable frequency) in **pseudowords** analysis was reliable on the RTs data: $F1\ (1, 38) = 68.13$, $p < .001$; $F2\ (1, 28) = 10.94$, $p < 0.005$, with longer RTs for pseudowords with high-frequency syllables.

Thus, the effects of syllable frequency and word frequency reported in Carreiras et al. (1993) were replicated with a different set of stimuli. The syllable frequency of words slowed RTs and increased error rates whereas word frequency facilitated performance. The main difference was observed on the analysis of errors rate: Carreiras et al. failed to find significant effect of syllable frequency while now syllable frequency was significant on words (F1) and pseudowords (F1 & F2), mirroring the RTs results. So, the syllable frequency effect is robust as it occurs with another set of materials.

[3] First of all, as in Experiment 1, word data were analysed separately in order to test the interactions between syllable frequency and word frequency. Although they were not significant, the inhibitory effect of first-syllable frequency is bigger in low-frequency words (a difference of 23 ms) than in high-frequency words (11 ms), replicating the pattern of Experiment 1. For the sake of brevity, we will not report these analyses in the present and the following experiment unless some different and relevant data arise.