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Effects of syllable neighborhood frequency in visual word recognition and reading: Cross-task comparisons

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During the process of visual word recognition readers do not identify words as a whole –specially long words–, but rather there are sublexical units that mediate between a word's constituent letters and the lexical level. One of the most important sublexical units is the syllable, especially in Romance languages such as French and Spanish. The syllable has been proposed as one of the most relevant functional units not only during speech perception (e.g., Mehler, Dommergues, Frauenfelder, & Segui, 1981; Sebastián, Dupoux, Segui, & Mehler, 1992; however, see Content, Meunier, Kearns, & Frauenfelder, 2001) but also during visual word recognition (e.g., Carreiras, Álvarez, & de Vega, 1993; Ferrand, Segui, & Grainger, 1996; Rapp, 1992; Spoehr & Smith, 1973; Taft & Forster, 1976; but see Brand, Rey, & Peereman, 2003). In the next section we review the evidence for syllabic processing, focusing especially on the syllable frequency effect, which is the variable manipulated in the present study. We will then present three experiments; these experiments employed different experimental tasks (speeded identification, lexical decision, and silent normal reading) and we will examine the similarities/differences comparisons across tasks. Finally, we will discuss the implications of our findings for the current models of visual word recognition and reading.

Syllabic processing in visual word recognition: the syllable frequency effect

One of the most relevant findings for the existence of syllabic processing in visual word recognition has been obtained by manipulating syllable frequency (e.g., Carreiras et al., 1993; see also Álvarez, Carreiras, & de Vega, 2000; Álvarez, Carreiras, & Taft, 2001; Conrad & Jacobs, in press; Perea & Carreiras, 1995, 1998). In their seminal paper, Carreiras et al. (1993) found that Spanish words composed of high-frequency syllables are responded to more slowly than words composed of low-frequency syllables. This effect has been found both in lexical decision (Álvarez et al., 2000, 2001; Carreiras et al., 1993; Conrad & Jacobs, in press; Mathey & Zagar, 2001; Perea & Carreiras, 1998) and progressive demasking tasks (Perea & Carreiras, 1995; Conrad & Jacobs, in press). The syllable frequency effect has been interpreted in terms of competition among word units in an interactive activation model (see Grainger & Jacobs, 1996): 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; see Pollatsek, Perea, & Binder, 1999, for a review of the literature on orthographic neighbors) are being activated in the process of visual word recognition, as usually considered, but also syllabic neighbors (i.e., words that share a syllable with the target word, especially the *first* syllable, e.g., *cosa-codo*; the Spanish for thing-elbow; see Taft & Forster, 1976). That is, the lexical unit corresponding to the high-frequency word *cosa* (the Spanish for thing) would be partially activated (or accessible) when the lower-frequency syllabic neighbor *codo* (the Spanish for elbow) is presented. It is worth noting that a number of other potential explanatory factors of the syllable frequency effect have been discarded: neither bigram frequency (Carreiras et al., 1993), orthographic neighborhood density/frequency (Álvarez et al., 2001; Perea & Carreiras, 1998), or morpheme frequency (Álvarez et al., 2001) can account for the previous findings. Furthermore, one proof of the reliability of this finding is that the effect has been replicated in other languages (e.g., French: Mathey & Zagar, 2001; German: Conrad & Jacobs, in press). Thus, the syllable frequency effect suggests that the syllable is a fundamental processing unit in visual word recognition in Spanish (and probably in other languages as well).

Further research has shown that the factor responsible for the inhibitory effect of syllable frequency does not seem to be the frequency of the syllable *per se*, but rather the number of higher frequency syllabic neighbors of the target word (Perea & Carreiras, 1995, 1998; see also Álvarez et al., 2001). In other words, the number of higher frequency syllabic neighbors appears to modulate the process of lexical access of multisyllabic Spanish words. As indicated above, syllabic neighbors may behave in a similar way to the "orthographic" neighbors (e.g., *cosa-casa*; thing-house): the syllabic neighbors words will compete in some way in the recognition process, and the degree of competition is a function of the relative frequency of the target word and its competitors (e.g., see Grainger & Jacobs, 1996, for a computational model of visual word recognition and lexical decision).

Contrary to the lexical decision and progressive demasking tasks, the syllable frequency effect is facilitative in the naming task (Carreiras & Perea, in press; Perea & Carreiras, 1996, 1998; see also Brand, Rey, Peereman, & Spieler, 2002, for evidence in French). Perea and Carreiras (1998) reported that disyllabic words with an initial high-frequency syllable were pronounced more rapidly than disyllabic words with an initial low-frequency syllable (see also Perea & Carreiras, 1995; Carreiras & Perea, in press). It is important to note that this effect occurs independently of lexical stress, bigram frequency, and seems to be restricted to the initial syllable (Carreiras & Perea, in press). This effect has been interpreted in terms of faster access of high-frequency syllables to the 'mental syllabary' involved at the level of the sublexical phonological output (Carreiras & Perea, 1993; Perea & Carreiras, 1998).

Taken together, the above-cited results can be accommodated within the framework of an interactive activation model of visual word recognition and naming that includes syllable-sized units. Ferrand et al. (1996) proposed one such model, in which syllable-sized units were implemented both in the sublexical input phonology and in the sublexical output phonology. Sublexical input phonology is thought to be structured syllabically: sublexical phonological codes (such as syllables) could receive activation from the letter level and send on activation to the word level, so that words that share one syllable can influence the process of word recognition (via lexical inhibition at the word level). The effects of syllable frequency in word/pseudoword naming are predicted to be facilitative because of the faster computation of the articulatory output units in the sublexical output phonology (see Ferrand et al., 1996). In other words, the syllable-sized output units can facilitate the articulatory response, so that items with higher frequency syllables can be synthesized more rapidly, and hence pronounced more rapidly than items with lower frequency syllables. Thus, the Ferrand et al. model can simultaneously cope with the presence of an inhibitory effect of syllable frequency in lexical decision and identification tasks as well as with the presence of a facilitative effect of syllable frequency in naming tasks.

Finally, converging evidence of the use of the syllable as a sublexical unit in Spanish has also been obtained with briefly/masked presented primes (masked priming technique; Forster & Davis, 1984) by Carreiras and Perea (2002) and Álvarez, Carreiras, and Perea (2003). For instance, Perea and Carreiras (2002; Experiment 3) used monosyllabic (*ZINC*) and CV.CV disyllabic words (*RA.NA*) as targets. The results showed a significant syllabic priming effect for the disyllabic words (*ra.jo-RA.NA* relative to *cu-fo-RA.NA*) whereas that monosyllabic words were not affected by related primes that shared the first two letters with the target (related condition: *ziel-ZINC*), or did not (unrelated condition: *flur-ZINC*). Likewise, Álvarez et al. (2003) found significant priming effects for disyllabic prime-target pairs that shared the first three letters and the first CV syllable (e.g., *ju.nas-JU.NIO*) relative to disyllabic pairs that shared the first three letters but not the first syllable (*jun.tu-JU.NIO*). Taken together, these findings strongly support the view that sublexical input phonology is structured syllabically, at least for languages with clear syllable boundaries (see also Domínguez, Cuetos, & de Vega, 1998, for evidence of syllabic priming effects with visible primes in Spanish).

The issue of the different word identification tasks and normal reading

Clearly, one major problem faced by any researcher investigating visual word recognition concerns the selection of the appropriate laboratory word identification task to test the proposed hypotheses. In the absence of a strong theoretical analysis of the different tasks (but see Ratcliff et al., in press, for a detailed analyses of the lexical decision task in terms of a diffusion-like decision process), and how they relate to the hypothesized basic processes involved in visual word recognition (the analysis of functional overlap proposed by Grainger & Jacobs, 1996; see also Grainger & Ferrand, 1996), we will compare the results of the same manipulation across two standard laboratory tasks (progressive demasking and lexical decision) and, more importantly, we will compare these results with a silent reading task in which the subjects' eye-movements are monitored.

Thus, the main goal of the present series of experiments was to shed more light on the role of the number of higher frequency syllabic neighbors (i.e., syllable neighborhood frequency) in word identification by embedding the target words in a normal sentence reading task. In the reading task, participants read the sentences while their eye movements were monitored, and fixation times on words in the target word region were used to examine the effects of the experimental manipulation. For comparison purposes, we also examined the same words in two laboratory word identification tasks. We chose the lexical decision task and the progressive demasking task because they have been studied most intensively in the research on lexical neighborhoods. (Because of the difficulty at creating the materials for the eye-movement experiment, we could not match the words across conditions in terms of the initial sound; for that reason, we did not conduct a parallel naming experiment.) To our knowledge there is only one published study (Schilling, Rayner, & Chumbley. 1998) that focused in depth on the comparison between normal reading and two laboratory word identification tasks (lexical decision and naming).

Leaving aside the issue of the higher ecological validity of the normal reading task, an additional reason for using the reading task to investigate syllable neighborhood frequency is that it offers a window on whether the effects observed occur relatively "early" or "late" in word identification (Perea & Pollatsek, 1998; Pollatsek et al., 1999). Because eye fixations in reading are relatively short (usually about 200-250 ms), one can examine whether effects are early (e.g., on the first fixation on the target word), intermediate (e.g., on later fixations on the target word), or late (e.g., on fixations after the target word has been left or on regressions back to the target word).

And last but not least, the evidence concerning word-beginnings in reading seems to suggest that the effect of a frequent (unconstraining) beginning may not be inhibitory (as apparently can be deduced from the research of Carreiras and colleagues) but rather it may be facilitative. Specifically, there is one earlier reading study that varied the initial "constraint" of a word at a letter level (not at a syllable level) in a reading task. Lima and Inhoff (1985) manipulated "constraint", defined by the number of words that began with the first three letters of the target word (e.g., *gymnastics* vs. *basketball*), and found that words with less constraint (*basketball*) had shorter first fixation durations than words with greater constraint (*gymnastics*) in a sentence like "They practice gymnastics/basketball for hours." (First-fixation duration is the duration of the first fixation on a target word.) Their finding thus can be interpreted as a facilitative effect on early processing due to a larger "neighborhood". This is not the only possibility, however, as the difference between their conditions may be due to the low initial trigram frequency of the words with smaller neighborhoods (see Pollatsek et al., 1999). Unfortunately, Lima and Inhoff (1984) did not report the values of other important eye-movement measures (e.g., total time on the target word, percentage of regressions back to the target word, among others), which makes more difficult the interpretation of their data. (For instance, the Lima and Inhoff experiments showed that the effect of "constraint" tended to vanish for gaze durations.) Clearly, it is of theoretical importance to examine the issue of syllable neighborhood frequency in a silent reading task.

The present experiments

The present study provides a further investigation of the effects of syllable neighborhood frequency (operationalized as number of higher frequency syllabic neighbors in the first syllable)[1] in three experimental paradigms: Speeded identification (the progressive demasking task), word-nonword classification (the lexical decision task), and silent fluent reading (eye-movement experiment). The same set of eighty word stimuli were tested in all three experiments, thus allowing cross-task comparisons not only of the variables under study, but also in terms of how the tasks cohere with respect to inter-item variability. To this end, a final combined analysis over all three experiments examines pairwise correlations between experiments. These analyses should help isolate task-independent and task-specific processes underlying effects of syllable neighborhood in visual word recognition and reading.

In the present series of experiments, we controlled for word-frequency, length, orthographic neighborhood (both orthographic neighborhood frequency and orthographic neighborhood size) while manipulating the number of higher frequency of syllabic neighbors (in the first syllable) of the target words (few vs. many). Bear in mind that the initial syllable seems to play a special role in visual word recognition (see Perea & Carreiras, 1998; see also Álvarez et al., 2000; Taft & Forster, 1976). In this light, the material was composed of pairs of words like *cabra* (goat) and *burra* (donkey). Note that the Spanish word c*abra* has forty-one higher frequency syllabic neighbors in the first syllable, whereas *burra* only has six higher frequency syllabic neighbors in the first syllable. We used the progressive demasking task in Experiment 1, the lexical decision task in Experiment 2, and the silent reading task in Experiment 3.

Experiment 1: Progressive demasking task

In the progressive demasking task, the presentation of a target word is alternated with that of a mask. On each alternation cycle, the target presentation time increases slowly while that of the mask decreases (i.e., the signal-to-noise ratio increases). The participant's task is to press a button as soon as the target word is identified. Compared to other tasks (e.g., lexical decision), progressive demasking reduces the rate of presenting the sensory information to the participant (i.e., the average RT, as measured from the onset of the alternation process, usually falls between 1 and 2 sec), thus effectively slowing the word identification process. Previous work using progressive demasking and related techniques has demonstrated the sensitivity of the paradigm to the influence of orthographic and syllabic neighborhood on word recognition (Carreiras, Perea, & Grainger, 1997; Grainger & Segui, 1990; Conrad & Jacobs, in press; Perea & Carreiras, 1995; Snodgrass & Mintzer, 1993; van Heuven, Dijkstra, & Grainger, 1998).

Method

Participants. Forty undergraduate students from the Universidad de La Laguna participated in this experiment in exchange for course credit. All were native speakers of Spanish and either had normal vision or vision that was corrected-to-normal.

Design and materials. The 80 target words were five letters in length. All the target words had frequencies of twenty-four or less per million in the Alameda and Cuetos (1995) count. The number of orthographic neighbors (N value) for the target words varied from 0 to 12. The 80 target words, which differed in the number of higher frequency syllabic neighbors (mean 3.3, range 0-9 vs. mean 40, range 25-93, in the groups with few and with many higher frequency syllabic neighbors, respectively, in the Cobos et al. count) were divided into 40 matched pairs; in each pair, the two words were matched on length, approximately matched on frequency (4.9 vs. 4.0 per million, respectively), orthographic neighborhood size (4.3 vs. 4.4, respectively), and number of higher frequency orthographic neighbors (2.2 in each group).

Procedure. Participants were tested individually in a quiet room. Presentation of the stimuli and recording of latencies were controlled by a PC computer. Word stimuli were presented in alternation with a pattern mask. Each presentation cycle was composed of a given stimulus word followed immediately by a pattern mask of seven hash marks (#######). On each successive cycle, the presentation of the stimulus was increased by 14 ms and the presentation of the mask decreased by 14 ms. The total duration of each cycle remained constant at 300 ms. Each trial consisted of a succession of cycles where stimulus presentation increased and mask presentation decreased. On the first cycle of each trial, stimuli were presented for 14 ms and the mask for 286 ms. On the second cycle, stimuli were presented for 28 ms and the mask for 272 ms, and so on. There was no interval between cycles. This succession of cycles continued until the participant pressed a response key on the computer keyboard to indicate that s/he had recognized the stimulus word. Response latencies were measured from the beginning of the first cycle until the participant's response. Participants were instructed to focus their attention on the center of the visual display and to press the response key with the forefinger of their preferred hand as soon as they had recognized the word. They were instructed to type in the identified word using the keyboard of the computer. Pressing the return key then initiated the following trial. Participants were asked to carefully check that they had correctly typed the word they thought they had been presented before initiating the following trial. Each participant received a total of 80 experimental trials, which were preceded by 12 practice trials. The whole session lasted approximately 15 min.

Insert Table 1 about here

Results and Discussion

The trials on which there were incorrect responses (4.1% of the total) and reaction times greater than 3.5 seconds (1.1% of the total) were removed from the response time analyses.

There was an inhibitory effect of 34 ms for having many higher frequency syllabic neighbors (1843 ms for the words with many higher frequency syllabic neighbors vs. 1809 ms for the words with few higher frequency syllabic neighbors), $F(1,39)=4.38$, $MSE=5189.9$, $p<.05$. For the error data, the effect of syllable neighborhood frequency had the same trend as in the RT data (i.e., more errors for the words with many higher frequency syllabic neighbors, 4.6%, than for the words with few higher frequency syllabic neighbors, 3.6%), but the effect was not significant, $F(1,39)=1.13$, $MSE=17.76$.

Thus, this experiment replicates previous findings with the progressive demasking task (in Spanish, Perea & Carreiras, 1995; for evidence in German, see Conrad & Jacobs, in press): words with higher frequency syllabic neighbors showed longer identification times than the words with few higher frequency syllabic neighbors.

Experiment 2: Lexical decision task

The design of this lexical decision experiment is straightforward. We used the same set of items as in Experiment 1. For the purposes of the lexical decision task, we added a set of eighty orthographically legal nonwords.

Method

Participants. Forty undergraduate students from the Universidad de La Laguna participated in this experiment in exchange for course credit. All were native speakers of Spanish and either had normal vision or vision that was corrected-to-normal. None of them had taken part in Experiment 1.

Design and materials. The target words were the same as in Experiment 1. A set of 80 orthographically legal nonwords used for the lexical decision task was created by changing a middle letter in words of similar length. Each participant saw all of the 80 target words and the 80 nonwords.

Procedure. Participants were tested individually in a quiet room. Presentation of the stimuli and recording of latencies were controlled by a PC computer. On each trial, a ready signal (*) was presented for 500 ms on the center of the screen. Next, the letter string was presented centered until the participant's response. Participants were instructed to press one of two buttons on the keyboard ("l" for yes and "a" for no, which had the labels "yes" and "no" on them) to indicate whether the letter string was a legitimate Spanish word or not. This decision had to be made as quickly and as accurately as possible. After an inter-trial interval of 1,500 ms, the next trial was presented. Each participant received 24 practice trials prior to the 160 experimental trials. The whole session lasted approximately 10 min.

Results and Discussion

The word trials on which there were incorrect responses (4.1% of the total) and reaction times greater than 1,500 ms or less than 300 ms (1.6% of the total) were removed from the response time analyses.

There was a small inhibitory effect of 7 ms for having many higher frequency syllabic neighbors (747 ms for the words with many higher frequency syllabic neighbors vs. 740 ms for the words with few higher frequency syllabic neighbors), but it was not significant ($p > .10$). For the error data, the inhibitory effect of syllable neighborhood frequency was significant (13.5% of errors for the words with many higher frequency syllabic neighbors vs. 10.9% of errors for the words with few higher frequency syllabic neighbors, $F(1,39)=12.14$, $MSE=10.82$, $p < .002$.

This experiment replicates an inhibitory effect of having many higher frequency syllabic neighbors (see Perea & Carreiras, 1998). One difference with the Perea and Carreiras (1998) experiment is that the effect in the present experiment occurred in the error data rather than on the RT data. Although it is somewhat desirable to obtain the effect on the RT data rather that on the error data, we must bear in mind that an effect in the error data and an effect in the RT data can be considered the two sides of the same coin: if participants were told that 13.5% was not an acceptable word error rate and, instead, they were asked to be as accurate in the condition with many higher frequency syllabic neighbors as in the condition with few higher frequency syllabic neighbors (10.9%). The only cell in which participants need to trade speed for more accuracy is the condition with many higher frequency syllabic neighbors. If they could do it, then the mean response time of 747 ms would go higher. Indeed, the presence of effects that sometimes occur in the error data rather than on the RT data is not new (for a few recent examples, see Perea & Rosa, 2000, 2003; Taft & Kougious, 2002).

Experiment 3: Eye-movement task

Experiments 1-2 essentially replicated earlier work using the progressive demasking task and the lexical decision task. That is, these experiments demonstrated that the presence of many higher syllabic neighbors interferes the identification of masked stimuli (Experiment 1) and "word" decisions (Experiment 2). We now wanted to determine whether an inhibitory syllable neighborhood frequency effect would be observed with the same words when people were engaged in silent fluent reading as opposed to identifying masked words or making lexical decision judgments.

The extension of Experiments 1-2 was relatively straightforward. We constructed 40 sentence frames, one for each matched pair of target words. As a result, each frame produced two sentences, one containing the target word with few higher frequency syllabic neighbors and the other containing the target word with many higher frequency syllabic neighbors (both in the same location in the sentence). It was not hard to embed the pairs of these words in sentence frames so that the two words were equally natural, even though the words were not synonyms, as in the sentence "La repentina muerte de la burra/cabra entristeció a los niños." ("The sudden death of the donkey/goat made the children sad."); note that *burra* has six higher frequency syllabic neighbors, whereas *cabra* has forty-one higher frequency syllabic neighbors. The key question was whether the sentence containing the word with few higher frequency syllabic neighbors was easier to read than the sentence containing the word with many higher frequency syllabic neighbors. Of particular interest was the duration of fixations on the target word and the region following it, and the pattern of regressions from the succeeding region back to the target word.

Method

Participants. Fifty-two students from the Universidad de La Laguna took part in the experiment in exchange for course credit. All were native speakers of Spanish and either had normal vision or normal vision when corrected by soft contact lenses. None of them had taken part in the previous experiments.

Materials. The stimuli were a set of 40 pairs of sentences that used the 80 target words of Experiments 1-2. The two members of each sentence pair were identical except for the target word (one target word having few higher frequency syllabic neighbors and the other having many higher frequency syllabic neighbors). Each sentence was no more than 80 character spaces in length, occupying one line on the cathode-ray tube (CRT) display screen; the target word was usually somewhere in the middle of the sentence and was never the first or last word of the sentence.

Design. Two lists were created, each containing 40 experimental sentences. Each list contained 20 sentences with a target word with few higher frequency syllabic neighbors and 20 sentences with a target word with many higher frequency syllabic neighbors. The presence of the target words was counterbalanced across the two lists, so that if a word with many higher frequency syllabic neighbors (e.g., *cabra*) appeared in one list, its corresponding target word with few higher frequency syllabic neighbors (*burra*) appeared in the other list. The two target words in the same sentence frame had the same number of letters and were of approximately equal frequency. Each subject saw one of the two lists and the order of the experimental sentences was randomized independently for each subject. Before reading the experimental sentences, each participant completed 8 trials with practice sentences to become familiar with the procedure.

Apparatus. Eye movements were recorded by a Fourward Technologies Dual Purkinje Eyetracker which has a resolution of less than 10 minutes of arc and the output is linear over the angle subtended by a line of text. The eyetracker was interfaced with a 486 PC-computer. The position of the eye was sampled every millisecond, and each 4 ms of eyetracker output was compared with the output of the previous 4 ms to determine whether the eyes were fixed or moving, and the computer stored the duration and location of each fixation for later analysis. The computer was also interfaced with a VGA monitor on which the sentences were presented. The display was 61 cm from the participant's eye and four characters equaled one degree of visual angle. Viewing was binocular, but eye movements were recorded from the participant's right eye.

Procedure. When a participant arrived for the experiment, he/ was seated looking at the monitor standing with his/her head on a chin rest, and the eyetracking system was calibrated. The calibration period usually lasted less then five minutes. After the calibration was completed, participants were told that they would be given sentences to read and that the purpose of the experiment was to determine what people look at as they read. Participants were told to read each sentence for normal comprehension. To ensure comprehension, they were asked to answer comprehension questions on one third of the sentences. Participants had little difficulty answering the questions correctly.

Data analysis. Several dependent variables were of major interest. The first group were measures of "first pass" processing on the fixated word: (1) the *first-fixation duration* (the duration of the first fixation on the target word) and (2) the *gaze duration* (the sum of the fixation durations on the target word before the reader left the target word; (3) the probability of fixating the target word. (For all of these analyses, the target region was defined as the target word plus the space that preceded it.) For both of the above fixation duration measures, trials were counted only when the reader initially fixated the word with a forward saccade; moreover, the measures are conditional – the averages are taken only over trials on which the word was not initially skipped. The second group of measures assessed processing after the reader left the target word on his or her "first pass" through the text. This included *spillover*, the duration of the first fixation after leaving the target word, the probability of making a regression back to the target word, the *total time* spent on the target word (the sum of all fixation durations on the target word including regressive fixations).

Results and Discussion

A small number of sentences were excluded from the analysis because of problems with monitoring the eye movements: less than 5% of the trials were eliminated either because there was a track loss while reading the sentence or because the participants were not fixating where they were supposed to when the sentence appeared.

First pass measures. Unlike the progressive demasking task and the lexical decision task, the effect of increasing syllable neighborhood frequency was facilitative in reading. This facilitative effect showed up in the three first pass measures, although it was significant only in the first fixation measure (see Table 1). First, target words with many higher frequency syllabic neighbors were skipped 0.9% less often that the target words with few higher frequency syllabic neighbors (although $F<1$). Second, the mean first fixation duration on target words with many higher frequency syllabic neighbors was 9 ms faster than that for target words with few higher frequency syllabic neighbors, $F(1,51)=4.94$, $MSE=429.9$, $p<.04$. Third, the mean gaze duration on target words with many higher frequency syllabic neighbors was 4 ms greater than that for target words with few higher frequency syllabic neighbors, although $F<1$. There was thus no indication of any inhibitory effect of increasing syllable neighborhood frequency in these early measures.

Insert Table 1 about here

Later measures and cumulative measures. Chronologically, the first measure of processing after the reader leaves the target word is the duration of the first fixation after leaving the target word ("spillover"). This measure is often "noisy" because this fixation could be either on the word following the target word or the word following that. The effect of increasing the number of higher frequency syllabic neighbors was facilitative, although quite small (2 ms) and obviously not significant ($F<1$). A second late measure of processing difficulty on the target word is the probability of regressing back to the target word. Again, the effect of increasing the number of higher frequency syllabic neighbors was facilitative, as readers regressed back to the target word 1.6% more often when the target words had few higher frequency syllabic neighbors, although this effect was again not statistically significant, $F<1$. A cumulative measure of target word processing that includes both first and second pass times is the total time spent on the target word: readers' total times were 10 ms longer on the target words when they had many higher frequency syllabic neighbors, although the effect was not significant, $F<1$.

In sum, the effect of increasing syllable neighborhood frequency in the reading task was facilitative in an early stage (first-fixation duration), but it disappeared later on (i.e., the effect did not even appear in the gaze duration and it had a small inhibitory trend in the total time on the target word).

Global Analyses of Experiments 1-3

Table 2 presents the Pearson correlations between the averages per item in a number of dependent variables (N=80) obtained in the different tasks used in Experiments 1-3. Not surprisingly, the mean RT and its corresponding percent error in the lexical decision experiment are the most highly correlated (.72). What is more interesting, however, is the very strong correlation between the progressive demasking task of Experiment 1 and the lexical decision task of Experiment 2 (.62), replicating the findings of Carreiras et al. (1997). This again suggests that the progressive demasking task shares many of the cognitive processes the lexical decision task, despite the potential “wordness” dimension involved in the lexical decision task and the potential “guessing” dimension involved in the progressive demasking task.

Insert Table 2 about here

Let's first examine the correlation of the two laboratory identification tasks with the reading task. RTs with the lexical decision task and the progressive demasking task correlate very weakly with an early measure of eye-movements such as the first-fixation duration (.12 and .14, with the lexical decision task and with the progressive demasking task, respectively). Nonetheless, lexical decision times and progressive demasking tasks correlate to a much higher degree with gaze durations (.49 and .34, respectively). Likewise, RTs with the lexical decision task and the progressive demasking task correlate significantly with a late measure of eye-movements such as the number of regressions back to the target word (.38 and .43, in the lexical decision task and the progressive demasking task, respectively) and with the total time on the target word (.50 and .44, respectively).

It is important to note the negligible correlation coefficient between the first-fixation duration with the other measures of eye-movements, except for the gaze durations (note, however, that the first-fixation duration is actually included in the gaze duration). In contrast, all the other eye-movement measures correlate highly with each other; the only exception was the correlation between gaze durations and the percentage of regressions back to the target word). Thus, the presence of a facilitative effect of the number of higher frequency syllabic neighbors in the first-fixation duration, but not in the other measures, may reflect an early process in which familiar beginnings are benefited in the parafovea. (We discuss this issue in the General Discussion.)

General Discussion

The main findings of the present series of experiments are as follows: 1) there is an inhibitory effect of the number of higher frequency syllabic neighbors in progressive demasking and lexical decision, replicating earlier research (Perea & Carreiras, 1998); 2) there is some early facilitative effect of the number of higher frequency syllabic neighbors in the reading task (first-fixation durations), which disappears in the other eye-movement measures; and 3) the cross-task comparisons show high correlation coefficients between lexical decision times and speeded identification times with the most relevant eye-movement measures (gaze durations, total time, percentage of regressions back to the target word), except with the first-fixation durations.

The role of syllabic neighbors in word identification tasks and reading

The results of Experiments 1 and 2 can be readily accommodated within an interactive activation model that incorporates a syllabic level of processing (see Carreiras et al., 1993; Perea & Carreiras, 1998). For instance, as stated in the Introduction, a word's higher frequency syllabic neighbors may be partially activated during word processing at the level of sublexical input phonology, and these neighbors may later may interfere (because of lateral inhibition) the unique identification of the target word. Thus, syllabic processing is probably phonological (rather than orthographic) in nature (see Álvarez et al., 2003; for evidence with the masked priming technique).

But can we reconcile the finding of an inhibitory effect of syllable neighborhood frequency in progressive demasking and in lexical decision with the facilitative effect of syllable neighborhood frequency in the first-fixation duration of the silent reading experiment? The finding of an early advantage for the condition with many higher frequency syllabic neighbors (e.g., *cabra*) over the condition with few higher frequency syllabic neighbors (*burra*) is consistent not only with the findings reported by Lima and Inhoff (1985) but also with an interactive activation model that incorporates a syllabic level of processing such as that described above. They key issue is that an effect that occurs only in the first-fixation duration is posited to tap very early processes of lexical access (see Inhoff, 1984). Given that readers process the *N* word when they are fixating the *N-1* word (see Reichle, Pollatsek, Fisher, & Rayner, 1998), it is very likely that on a number of trials, readers were processing the target word when they were processing the previous word. Note that when there is no parafoveal letter information, even the ubiquitous word frequency effect is negligible in the first-fixation duration; this strongly suggests that the first-fixation duration is related to early lexical processes. In an interactive activation model with a syllabic level of processing, words composed of high-frequency syllables produce a higher degree of "wordness" (i.e., lexical activation) than the words composed of low-frequency syllables at the early stages of word processing. It is only when the task requires unique word identification when -because of inhibition at the word level- words composed of low-frequency syllables enjoy an advantage over words with high-frequency syllables. To further examine this possibility, we conducted a post hoc regression analysis on the first-fixation durations with log of word-frequency, the number of higher frequency syllabic neighbors, the number of lower frequency orthographic neighbors (see Pollatsek et al., 1999), and the number of higher frequency orthographic neighbors. The results showed some facilitative effect for the number of higher frequency syllabic neighbors ($t(76)=2.06$, $p<.05$) and for the number of lower frequency orthographic neighbors ($t(76)=2.39$, $p<.02$), but no signs of an effect of word-frequency ($t<1$). (Note that the facilitative effect of these predictors vanished in the other measures and, in contrast, a lexical factor such as word-frequency had an impact on these other measures.) Interestingly, the finding of an early effect of the number of lower frequency orthographic neighbors is consistent with the data presented by Pollatsek et al. (1999). In sum, fluent reading is a fast process that may exploit how frequent a given orthographic/syllabic structure is, so that familiar configurations may enjoy some benefit over unusual configurations in a first stage. Interestingly, the number of measure of lower frequency orthographic neighbors has been posited to be the responsible of the facilitative effect of orthographic neighborhood in lexical decision (Paap & Johansen, 1994; Pollatsek et al., 1999), and indeed, the number of lower frequency orthographic neighbors yielded a facilitative effect in a parallel regression analysis with the present lexical decision data.

Thus, the presence of an early advantage of syllable neighborhood frequency (9 ms) in the first fixation on the target word, and a slight disadvantage of syllable neighborhood frequency (10 ms) in the total duration on the target word can be readily explained in this modified interactive activation model. One strong prediction from this account is that, in a lexical decision task, syllable neighborhood frequency should be modulated by the instructions given to the participants: if accuracy is stressed over speed (i.e., unique word identification is required), an inhibitory effect is expected; in contrast, if speed is stressed over accuracy, the inhibitory effect should vanish and a facilitative effect could be found. Current research in our lab is exploring this issue.

Clearly, the distinction between matching on the basis of global familiarity (i.e., the overall similarity of an input pattern to the collective content of the internal lexicon) and retrieval through integration (i.e., unique word identification) is common in many models of memory (see Reichle et al., 1998). In order to explain this phenomenon, it is important to briefly examine the most popular quantitative model of eye movements in reading, the E-Z Reader model (Reichle et al., 1998; Reichle, Rayner, & Pollatsek, in press). In the E-Z Reader model, an early measure of familiarity, rather than the completion of lexical access, serves as a signal to move the eyes to the following word. We believe that, on a number of trials, the reader uses this early measure of familiarity as a measure of "wordness" of the stimulus in a lexical decision task (in a similar way to the Σ criterion in the Grainger & Jacobs, 1996, multiple read-out model). After all, the average adult participant is not used to discriminate words from pseudowords in her/his daily life, and s/he may well take into account some cues used in normal reading. In this light, it is not surprising that responses to words with many lower frequency orthographic neighbors are faster than the responses to words with few lower frequency orthographic neighbors in the lexical decision task (e.g., see Pollatsek et al., 1999), as also found in the present lexical decision data. Interestingly, the present reading data and the reading data of Pollatsek et al. (1999, Experiment 3) suggest that there may be facilitative effects early in processing due to having more lower frequency orthographic neighbors when the number of higher frequency orthographic neighbors was held constant.

In sum, eye movements are a valuable source of information on the time course of processing during reading. Effects that occur early (i.e., before or while the target word is fixated) are likely to be chiefly reflecting early lexical processes, whereas later effects are likely to be reflecting post-access/verification processes as well. Indeed, as stated above, the signal to leave a word in the E-Z Reader model (which is the primary determinant of first-fixation duration) may not be completion of lexical access, but rather a partial stage of lexical processing. Indeed, the slow correlation coefficients between first-fixation duration and the other measures of eye-movements (except for gaze durations; keep in mind that gaze duration equals to first-fixation durations when there are no refixations) strongly suggest that a measure such as first-fixation duration does not tap the same processes as most other measures (e.g., total time on the target word). Given the high correlation coefficients between lexical decision time (or progressive demasking time) with gaze durations, total time, or percentage of regressions back to the target word, it seems that the lexical processes involved in these measures are –to some degree- the same. In contrast, first-fixation duration seems to tap a very early component of the process of lexical access, which may be related to the processing of the target word when the eye is still fixating the previous word.

The discrepancy between the results obtained in laboratory word identification tasks such as lexical decision and silent reading tasks is not new. For instance, Pollatsek et al. (1999) found a facilitative effect of orthographic neighborhood size in a lexical decision task; in the parallel reading task with the same materials, there were some hints of a facilitative effect in early measures, whereas the effect was inhibitory in late measures such as total time or the percentage of regressions back to the target word. In the present paper, however, the inhibitory effect due to the syllabic neighbors was not powerful enough to be significant in the total time on the target word (there was a nonsignificant 10 ms effect in the predicted direction). One reason for the weakness of the effect could have been due to the fact that -because of the difficulty of selecting appropriate pairs of stimuli for the sentence frames in the reading task- we only manipulated syllable frequency (or rather number of higher frequency syllabic neighbors) in the first syllable. A more extreme manipulation would be necessary to examine this issue further.

Conclusions

To summarize, the present experiments have shown that the syllable plays an important role in the recognition of visual words in Spanish. This results are consistent with a growing body of data that indicate that, upon the visual presentation of a word, syllabic neighbors affect the speed of lexical access. We have presented additional data across three different experimental paradigms that support this conclusion. Although several recent experiments has called into question the role of the syllable in visual word recognition (e.g., Brand et al., 2003) results from different labs and languages that suggests that the syllable is an important sublexical unit, even in non-Romance languages (e.g., German: Konrad & Jacobs, 2003; Korean: Cho, Son, & Nam, 2003).

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Table 1. Measures of reading in Experiment 3

Measure of Reading	Few HF Syll.N	Many HF Syll.N	Difference
First-fixation duration on the target word	266	257	9 *
Gaze duration on the target word	338	335	4
Probability of skipping target words	6.8%	5.9%	0.9%
Duration of first fixation after target word	235	233	2
Percent of regressions back to target word	18.6	17.0	1.6%
Total time on target word	443	453	-10

*p<.05

Table 2
Pearson Correlations Coefficients among the experimental tasks

Correlations of RT among tasks

	PDT	LDT	LDE	FF	GD	TT
LDT	.62 *					
LDE	.63 *	.72 *				
FF	.14	.12	.09			
GD	.34 *	.49 *	.40 *	.49 *		
TT	.44 *	.50 *	.53 *	.16	.47 *	
REG	.43 *	.38 *	.49 *	.06	.10	.63 *

*p<.01

Note:
PDT: Progressive demasking time
LDT: Lexical decision time
LDE Lexical decision (error rates)
FF: First-fixation duration
GD: Gaze duration
TT: Total time
REG: Percentage of regressions back to the target word

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[1] Not surprisingly, in the set of words used in the present study there was a strong correlation between the number of higher frequency syllabic neighbors in the first syllable and the log of syllable frequency of the first syllable, r=.82.