Syllables and bigrams: Orthographic redundancy and syllabic units affect visual word recognition at different processing levels.

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Abstract

Over the last decade, there has been increasing evidence for syllabic processing during visual word recognition. If syllabic effects would prove to be independent from orthographic redundancy, this would seriously challenge the ability of current computational models to account for the processing of polysyllabic words. Three experiments are presented to disentangle effects of the frequency of syllabic units and orthographic segments in lexical decision. In Experiment 1 we obtained an inhibitory syllable-frequency effect that was unaffected by the presence or absence of a "bigram trough" at the syllable boundary. In Experiments 2 and 3 an inhibitory effect of initial syllable-frequency but a facilitative effect of initial bigram-frequency emerged when manipulating one of the two measures and controlling for the other in Spanish words starting with CV-syllables. We conclude that effects of syllable-frequency and letter cluster frequency are independent and arise at different processing levels of visual word recognition. Results are discussed within the framework of an interactive activation model of visual word recognition.

Introduction

Reading is one of the basic cognitive skills necessary for modern life. Much research in the field of cognitive psychology has focused on reading and computational models have been constructed to simulate the process of visual word recognition. However, while most words in many languages are polysyllabic, most current computational models deal exclusively with the processing of monosyllabic words (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; Ziegler, Perry, & Coltheart, 2000; Zorzi, Houghton, & Butterworth, 1998; but see Ans, Carbonnel, & Valdois, 1998 for an exception). Whether and how polysyllabic words are segmented into their syllabic constituents during silent reading in different orthographies is still an open question. The first evidence for the assumption of syllabic processing was provided for the English language (e.g., Prinzmetal, Treiman, & Rho, 1986; Spoehr & Smith, 1973; Tousman & Inhoff, 1992). However, one important argument against the proposal of syllables being functional units of visual word recognition was formulated by Seidenberg (1987, 1989): He argued that a typical feature of orthographic redundancy within polysyllabic words could explain such empirical findings without any necessary reference to syllabic units: the bigram forming the boundary between two syllables is typically less frequent than intra-syllabic bigrams and therefore what might appear to be evidence for syllabic parsing could also be understood as the consequence of purely orthographic processing (but see Rapp, 1992; Carreiras & Marín, submitted).

More recently, a new approach towards the investigation of syllabic processing has been taken by research in Spanish, which, unlike English, has a shallow orthography with transparent syllabic structure: The finding of an inhibitory effect for the positional frequency of a word’s initial syllable, first reported by Carreiras, Álvarez, and de Vega (1993) has since been successfully replicated for two other languages, French (Mathey & Zagar, 2002), another Roman language, and German (Conrad & Jacobs, 2004), a non-Roman language. Words starting with a high-frequency syllable, a syllable that also forms the initial syllable of many other words, are responded to faster in lexical decision than words with low initial syllable-frequency. In addition, syllable frequency has been shown to influence neurocognitive correlates of the reading process, such as event related potentials (Barber, Vergara, & Carreiras, 2004; Hutzler et al., 2004a) and hemodynamic responses (Carreiras, Mechelli & Price, 2006). Some of the studies reporting syllable frequency effects in lexical decision also tried to dismiss the criticism of Seidenberg (1987) by using only words that did not show the typical pattern of a bigram trough at the syllable boundary (e.g., Carreiras et al., 1993; Perea & Carreiras, 1998). Successfully replicating the syllable-frequency effect, these studies showed that the presence of a bigram trough at the syllabic boundary is at least not a necessary condition for obtaining such a syllabic effect. Thus, the bigram trough hypothesis doesn’t seem to be a sufficient explanation for the apparent syllabic segmentation of polysyllabic words. Instead, the syllable-frequency effect is generally interpreted as evidence for an automatic syllabic segmentation of visually presented words: after a syllabic segmentation of the input, the first syllable activates the representations of words sharing this syllable in identical position and competition between these is responsible for the observed delay in the processing of words with high-frequency initial syllables (e. g., Perea & Carreiras, 1998).

Reconciling the view of syllables as functional units of visual word recognition and the importance of orthographic redundancy, Doignon and Zagar (2005) showed that the tendency for illusory conjunctions following syllabic structure was strongest when bigram troughs coincided with the syllable boundary of bisyllabic French words. Illusory conjunctions for syllabic units were attenuated but generally still observable when the syllable boundary did not coincide with a bigram trough[1]. Doignon and Zagar (2005) concluded that both phonological – relying on phonological syllables - and orthographic processing –relying on bigram troughs – would characterize the segmentation of orthographic word forms.

In any case, most current computational models would probably fall short in accounting for polysyllabic word processing being mediated by syllabic units because of their lack of syllabic representations. However, the question of whether the processing of syllabic units in visual word recognition occurs independently of orthographic redundancy or letter cluster frequency is not yet resolved. This is because a high-frequency syllable can generally also be described as a high-frequency letter cluster, independently of syllabic structure. Thus, regarding the nature of the syllable frequency effect, it remains to be shown that a cohort of competing word representations would in fact be activated by the target's initial syllable rather than by an initial letter cluster. In other words, it is unclear whether this empirical effect really reflects syllabic processing or whether it could also be understood as an effect of the frequency of letter clusters that are not syllabically defined.

The difficulty of making a clear statement regarding the nature of the syllable frequency effect is a general problem in the literature on syllable frequency effects in lexical decision. Although the syllable is mostly understood as a phonological concept, it is unclear – even when assuming that the effect were due to syllables and not to non-syllabically defined letter clusters - whether this effect has to be attributed to phonological syllables or to their orthographic representations. The main reason for this is that the manipulated variable in all available studies was orthographic syllable frequency – being hard to disentangle from phonological syllable frequency at least in shallow orthographies as Spanish and German. Some empirical evidence for a phonological base of syllabic effects in visual word recognition has been provided by Álvarez, Carreiras and Perea, (2004). They reported similar priming effects for primes that matched only the phonological but not the orthographic initial syllable of a target word compared to primes that matched both the phonological and the orthographic initial syllable of the target. More recently, Mathey, Zagar, Doignon and Seigneuric (2006) made a theoretical proposal of how effects related to both the processing of phonological syllables and orthographic letter clusters could be integrated into the architecture of an interactive activation model. They presented empirical data from a lexical decision task where an inhibitory initial syllable frequency effect occurred only for words starting with a high-frequency letter cluster. In the presence of a low-frequency letter cluster at the word beginning syllable frequency rather seemed to yield facilitation of word processing (Experiment 2 of Mathey et al., 2006). They concluded that a phonological route containing syllabic units was activated via orthographic redundancy. However, the empirical data is scarce and not completely conclusive[2]. Therefore, given the important theoretical impact of this question, clearly more empirical data is needed for a better understanding of the relation between orthographic redundancy and syllabic processing.

Generally, and in contrast to syllabic effects, effects of the frequency of letter clusters or of orthographic redundancy could theoretically be accounted for by current computational models. Empirical effects related to syllabic units could be accounted for by processing mechanisms sensitive to orthographic redundancy in the two following ways:

1. Any apparently syllabic segmentation could be achieved by a processing mechanism sensitive to the presence of a bigram trough that typically occurs at the syllabic boundary (Seidenberg 1987; 1989).
2. Regardless of syllabic structure, any effect of the frequency of a syllabic unit could arise as an effect of the frequency of the letter cluster representing the syllable. This would be in line with the findings of Schiller (1998; 2000) who stated that segmental overlap

rather than syllabic congruency was influencing primed word naming - see also Experiment 1 of Mathey et al. (2006) showing an inhibitory effect for the frequency of a word’s initial letter cluster not only when these letters were the initial syllable but also when they formed the beginning of a monosyllabic word.

Given the systematic relation between syllable-frequency and letter cluster frequency, the claim for a round of revision of computational models of visual word recognition (e. g., Álvarez, Carreiras, and Taft, 2001; Carreiras et al, 1993; Conrad & Jacobs; 2004; Perea & Carreiras, 1998) would take another perspective if syllabic effects can be seen as effects of orthographic redundancy or at least cannot reliably be distinguished from these. In this case, polysyllabic word processing might successfully be simulated applying the principles of modeling monosyllabic word processing without the involvement of syllabic representation units.

The present study addresses the question of the relatedness of syllabic and orthographic processing in the following ways: Experiment 1 readdresses the bigram trough hypothesis examining whether there are comparable effects of syllable-frequency in the presence and in the absence of a bigram trough at the syllabic boundary. Experiment 2 aims to replicate the syllable-frequency effect while controlling for the frequency of the letter cluster forming the initial syllable (the first bigram in words starting with a CV syllable). Experiment 3 is conducted to see if there is any effect of initial bigram-frequency for bisyllabic words when syllable-frequency is controlled for (for effects of bigram-frequency and positional letter frequency in monosyllabic word processing, see Massaro & Cohen, 1994; Grainger & Jacobs, 1993). The existence of qualitatively different processing mechanisms during visual word recognition related to syllable-frequency and to bigram-frequency, would seriously question the ability of computational models that do not include syllabic representations to account for the processing of polysyllabic words. Whereas adding a layer of syllabic representations might be the first step of solving this problem at least for localist connectionist models, such a pattern of results would be a substantial challenge for connectionist models that don't contain any representational units. However, if no independent effects of syllable and bigram-frequency are obtained, then current computational models could easily be extended to account for polysyllabic word reading without the need to implement a specific syllabic processing mechanism.

Experiment 1

Some empirical studies have already shown that the syllable-frequency effect can be obtained when words do not show the critical pattern of a bigram trough at the syllabic boundary. In doing so they contradicted the idea that the effect would only occur because orthographic redundancy offered a segmentation device for the extraction of the relevant sublexical unit (the syllable or the correspondent letter cluster). However, it has never been experimentally tested whether syllable-frequency effects and bigram troughs really have any type of systematic relation within the process of visual word recognition. That is, even if syllabic effects can be obtained without the presence of a bigram trough at the syllable boundary, a hypothesis taking into account the proposals of Mathey et al. (2006) and Doignon and Zagar (2005) could be that a bigram trough at the syllable boundary would facilitate the syllabic parsing process and syllable frequency effects should therefore be more pronounced in the presence than in the absence of such a pattern. In turn, a syllable frequency effect that would prove to be unaffected by the presence or absence of a bigram trough at the syllable boundary would rule out the "bigram trough hypothesis" as a possible source of syllabic processing in visual word recognition at least in Spanish. This is an issue that studies using only words not showing this critical bigram trough pattern have not completely resolved. On the contrary, using such a specific control means to implicitly acknowledge that bigram troughs would be important for the processing of syllables. This is an important outstanding question for a more detailed understanding of the relation between orthographic redundancy and syllabic processing. Experiment 1 directly manipulates the frequency relation between the bigram at the syllabic boundary and the remaining bigrams of a bisyllabic word. A syllable-frequency manipulation as a second experimental factor will provide information about any hypothetical modulation of the syllable-frequency effect in lexical decision depending on bigram troughs.

Method

Participants

Forty-six students of the University of La Laguna participated in the experiment.

Stimuli and Design

108 bisyllabic Spanish words were selected from the LEXESP database (Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000) according to the orthogonal combination of two factors in a within-participant 2x2 design: relative frequency of the bigram at the syllable boundary (relative to the mean frequency of the remaining intra-syllabic bigrams; presence vs. absence of a bigram trough at the syllable boundary) and positional frequency of the first syllable (high vs. low). E.g., "*li-*" is a high-frequency first syllable in Spanish whereas "*fo-*" is a low-frequency initial syllable. Accordingly, the word "lila" (purple) was placed in the "bigram trough - high syllable-frequency" category because of the relatively low frequency of the bigram "*il*" (relative to the mean frequency of the intra-syllabic bigrams "li" and "la") whereas the word "liso" entered the "no bigram trough - high syllable-frequency" category because "*is*" is a relatively frequent Spanish bigram (compared to the mean frequency of "li"

and “so”). The entry of the words “foto” and “foca” into the two different conditions for low syllable-frequency words was determined by the different relative bigram frequencies of *“ot”* (low) and *“oc”* (high). Syllable frequencies and bigram frequencies were computed on the base of all bisyllabic entries in the LEXESP database. Syllable frequency measures for all experiments in the present study refer to orthographic syllables given in this database. Syllable frequencies were computed position-specific: a first syllable’s frequency relates to all bisyllabic words sharing this syllable in first position, a second syllable’s frequency relates to all bisyllabic words sharing this syllable in second position. Because the focus of the present study is to investigate the relation between syllabic processing and orthographic redundancy we computed all bigram frequency or letter cluster frequency measures used for the present experiments analogously. All bigram frequencies are also computed position-specific referring to all bisyllabic entries in the database. All syllable and bigram frequency measures are token counts. Previous studies on syllable frequency effects had uncritically either used the token (e.g., Conrad & Jacobs, 2004) or the type syllable frequency measure (e.g., Álvarez et al, 2001) as independent variable, but a recent study has shown that – although the two measures are highly correlated – it is the token and not the type measure of syllable frequency that is driving the inhibitory syllable frequency effect in lexical decision (Conrad, Carreiras, & Jacobs, 2007).

A word was entered in the “bigram trough at the syllable boundary” condition when the mean frequency of all intra-syllabic bigrams (preceding or following the syllable boundary) was at least about 1000 per million occurrences superior to the one’s at the inter-syllabic boundary. In order to enter the “no bigram trough at the syllabic boundary” condition, a word’s inter-syllabic bigram’s frequency had to be superior (at least about 200 per million occurrences) to the mean frequency of all intra-syllabic bigrams. The ranges for initial syllable frequency were the following: less than 300 per million occurrences for low syllable frequency and more than 600 per million occurrences for high syllable frequency words. Words were matched across cells for length, word surface frequency, mean frequency of all bigrams, positional frequency of the second syllable, frequency of the letter cluster forming the second syllable, number of orthographic neighbors and number of higher frequency orthographic neighbors. Word stress was also controlled for. Between two and four words in each experimental condition containing twenty-eight words had ultimate stress, all other words had penultimate stress. Characteristics for words used in Experiment 1 are shown in Table 1[3]. As a consequence of the special selection criteria for the material in the experiments of the present study, it was unavoidable that some initial syllables appeared repeatedly within the words of one experimental condition. In order to prevent that repetition of initial syllables would influence participants' performance, for each experiment of the present study, filler items with alternative initial syllables were used in order to provide a more natural reading context. Nonwords for all experiments in this study were constructed by combining the first syllable of a word stimulus with another syllable that exists as a second syllable in Spanish. Thus, initial syllables did not differ between words and nonwords and all nonwords were pronounceable and orthographically legal.

<Table 1 about here>

Apparatus and Procedure

Stimuli were presented in lowercase letters using Courier 24 type font on the computer screen. Participants were instructed to make a decision concerning the lexicality of the stimulus as quickly and as accurately as possible, pressing a "yes"-button for a word and a "no"-button for a nonword. Response buttons were located on the keyboard of the computer. Stimulus presentation and response recording was controlled by EXPE 6.02 software (Pallier, Dupoux, & Jeannin, 1997). The stimulus list contained 250 words (108 experimental stimuli and 142 filler items) and 250 nonwords. The order of appearance of the stimuli was randomized for each participant. The stimulus remained visible until any response was given with an inter-trial interval of 1000 ms. There were ten initial training trials. The whole experiment lasted about twenty minutes.

Results and Discussion

Mean correct response latencies and error percentages (see Table 2) were submitted to separate analyses of variance (ANOVAs) by participants and by items (F1 and F2, respectively). Response latencies differing more than two standard deviations from the mean for each participant and experimental condition were excluded from the analyses. This led to the exclusion of 4.6% of the data of Experiment 1. Ten of the word stimuli in Experiment 1 had to be excluded from the analysis, because their corresponding mean error rates were higher than 45%. The same exclusion criteria for outlier rejection and for the exclusion of error prone word stimuli were applied in all analyses presented in this study.

Words were responded to 19 ms slower when they had a bigram trough at the syllabic boundary than when they had not. This mean difference was significant only in the analysis over participants, F1 (1,45) = 7.15, $p < .02$, $\eta_p^2 = .137$; F2 (1,94) = 0.52, $p > .4$, $\eta_p^2 = .006$. There was no effect on error rates. Syllable-frequency caused significant effects on both response latencies and error rates: words were responded to 42 ms slower when starting with a high- than with a low-frequency syllable, F1 (1,45) = 24.31, $p < .0001$, $\eta_p^2 = .351$; F2 (1,94) = 5.79, $p < .01$, $\eta_p^2 = .058$. Consistently, more errors (11.3% vs. 7.5%), occurred for words starting with high- than with low-frequency syllables, F1 (1,45) = 22.81, $p < .0001$, $\eta_p^2 = .336$; F2 (1,94) = 3.46, $p < .07$, $\eta_p^2 = .035$. Importantly, there was no interaction between the effects of the two factors, either in response latencies, $p > .9$, or in error rates, $p > .3$.

<Table 2 about here>

One might wonder to what degree this pattern of results - suggesting no importance of bigram troughs for the syllable frequency effect - might be influenced by the fact that a relatively large number of error prone items were excluded from the analyses. In order to verify if the lack of significance of the main effect of bigram trough in the item analysis and the absence of an interaction of this effect with the syllable frequency effect are due to this loss of statistical power we conducted additional ANOVAs, using all words presented in the experiment.

This time we obtained an inhibitory syllable frequency effect of 44 ms, F1 (1,45) = 27.66, $p <.0001$, $\eta_p^2 = .381$; F2 (1,104) = 6.67, $p <.01$, $\eta_p^2 = .059$. More errors (18.9% vs. 10.7%), occurred for words starting with high- than with low-frequency syllables, F1 (1,45) = 79.44, $p <.0001$, $\eta_p^2 = .638$; F2 (1,104) = 4.47, $p <.03$, $\eta_p^2 = .040$. A main effect of bigram troughs at the syllable boundary was still present in the participant analysis with words being responded to 16 ms slower when having a bigram trough at the syllable boundary, but again, this effect was far from being significant in the analysis over items, F1 (1,45) = 5.15, $p <.02$, $\eta_p^2 = .103$; F2 (1,104) = 0.32, $p >.5$, $\eta_p^2 = .003$. No effect for this factor was obtained on error rates. Regarding response latencies, again, there was no interaction between the effects of the two factors, $p>.9$, but such an interaction was observed in the error data, with a syllable frequency effect on error rates being more pronounced in the presence than in the absence of a bigram trough at the syllable boundary (20.6% vs. 9.8% relative to 17.2% vs. 11.6%), F1 (1,45) = 8.16, $p <.006$, $\eta_p^2 = .154$; F2 (1,104) = 0.47, $p >.4$, $\eta_p^2 = .004$. But note that this effect was significant only in the analysis over participants - where it had failed to reach statistical significance after the exclusion of highly error prone items. We therefore believe that this specific effect is best attributed to idiosyncratic characteristics of some words in the experimental material the exclusion of which from the analyses has not systematically affected the results of Experiment 1 in general.

The outcome of Experiment 1 confirms that the appearance of an effect of syllable-frequency does not depend on the presence of a bigram trough at the syllabic boundary. Importantly, the relation between these two phenomena was directly addressed for the first time. It turned out that the relative frequency of the bigram forming the syllabic boundary has absolutely no impact on the size of the syllable-frequency effect. This suggests that bigram troughs do not modulate syllabic processing at all, at least in Spanish. One remaining question is how the processing advantage (19 ms) for words not showing the bigram trough pattern might best be interpreted when a relation between bigram troughs and syllabic processing is not assumed. In fact, the manipulation characterizing the material of Experiment 1 involves not only the specific position of a relatively low frequency bigram (at the syllable boundary or not) but also has some impact on overall features of orthographic redundancy. As evident from Table 1, the mean frequency of all bigrams of a word did not differ significantly between words in the two conditions of the bigram trough manipulation (presence vs. absence), but it tended to be higher for words without bigram troughs at the syllable boundary.

Moreover, words with the typical bigram trough pattern at the syllable boundary often comprise at least one bigram of considerably low absolute frequency, which is not necessarily the case for words without a bigram trough at the syllable boundary. This variable had not been taken into account for the selection of the experimental material. Reanalyzing the material, we found a significant difference between the two conditions of the bigram trough manipulation regarding the frequency of the least frequent bigram of a word – computed regardless of whether this bigram formed the syllable boundary or not. Words with a bigram trough at the syllable boundary often contained one bigram the frequency of which was much lower than the respective frequencies of all bigrams in words without a bigram trough at the syllable boundary. It might well be the case that this specific feature of orthographic redundancy – the presence of one very low-frequency bigram within the orthographic word form – might explain why words with a bigram trough at the syllable boundary were responded to slower than words without such a bigram trough. Such an effect would not necessarily have anything to do with the specific position of this low frequency bigram at the syllable boundary – in other words, it might have no relation to a word's syllables or to syllabic processing.

We tested this hypothesis running a multiple regression analysis of the data of Experiment 1. Beside word surface frequency and the frequency measures of the first and the second syllable, the following bigram frequency measures were entered as predictors for response latencies in Experiment 1: the frequency of the bigram at the syllable boundary, the mean frequency of all intra-syllabic bigrams (both being related with syllabic structure) and the frequencies of the words' least frequent and highest frequent bigram (no relation to syllabic structure). All these token frequency measures were log-transformed before being entered into the regression model. Multiple regression analysis revealed a significant facilitative effect of word frequency, F1 (1,97) = 31.58, p <.0001, and a significant inhibitory effect of initial syllable frequency, F1 (1,97) = 7.92, p <.007. In addition, there were significant facilitative effects for the frequency of both the highest-frequent, F1 (1,97) = 6.05, p <.02, and the least-frequent bigram within a word, F1 (1,97) = 4.77, p <.04. No other effects were statistically significant. Coefficients of correlations and partial correlations between predictors and the dependent variables are given in Table 3.

It is especially interesting that a hypothetical influence of the frequency of the bigram at the syllable boundary was partialized out by the multiple regression analysis. An effect of this bigram's frequency as suggested by the ANOVAs computed on the experimental data is apparently not due to the fact that this bigram is straddling the syllable boundary. We conclude that the bigram trough effect in Experiment 1 is best understood as an overall orthographic redundancy effect. Bigram frequency seems to generally enhance the processing of orthographic word forms and a very low frequency bigram slows down this processing regardless of whether this bigram is located at the syllable boundary or not.

<Table 3 about here>

The most important outcome of Experiment 1, however, is the absence of an interaction between the effects of syllable-frequency and of the presence or absence of a bigram trough at the syllabic boundary in the ANOVA results, suggesting that syllabic effects are independent of orthographic redundancy in terms of bigram troughs at the syllable boundary. It might be argued that these results are incompatible with the ones of Doignon and Zagar (2005) who had reported an attenuation of the illusory conjunction effect for syllabic units when the syllable boundary did not coincide with a bigram trough. But there is an important difference between the illusory conjunction paradigm and the lexical decision task. The latter one is generally understood as assessing lexical access, which is not necessarily required in the former one. The fact that participants in the illusory conjunction task perceive two letters as being more or less related as a function of both syllabic organization and orthographic redundancy – and that in consequence the specific illusory conjunction effects can cancel each other out – does not necessarily imply that a mediation of lexical access by phonological syllables as we propose it has to be influenced by orthographic redundancy or bigram troughs. The results of Doignon and Zagar (2005) suggest that both types of information (syllabic and orthographic) can make a sublexical unit more salient. But they would not allow for any exact conclusions about how both types of processing mechanisms would interact during the process of lexical access as assessed by the lexical decision task. Bigram troughs and orthographic redundancy may well play an important role for the reading process in some orthographies. The point of Experiment 1 is to show that syllabic processing during word reading – as reflected by the syllable frequency effect - at least in Spanish is unaffected by bigram troughs.

Furthermore, the discrepancy between the effects of Doignon and Zagar (2005) and those presented in the present study might be an interesting case for a cross-linguistic perspective. We will refer to this issue in the General Discussion. In any case, the results of Experiment 1 don't allow the conclusion that the syllable frequency effect or syllabic processing in general were completely independent of orthographic redundancy. The frequency of the letter cluster being the syllable of words in Experiment 1 was always higher for high syllable-frequency words than for low syllable-frequency words. Therefore, it is important to examine whether the syllable frequency effect could be understood as an orthographic letter cluster frequency effect, because this would strongly question the syllabic or phonological nature of this effect.

In Experiment 2 we tested whether the standard effect of first syllable frequency can be obtained when controlling for initial letter cluster frequency. A syllable frequency effect that would prove to be independent from the syllable's letter cluster's orthographic frequency would be an important argument for syllabic processing in visual word recognition.

Experiment 2

Method

Participants

Forty-six students of the University of La Laguna participated in the experiment.

Stimuli and Design

72 bisyllabic Spanish words were selected from the LEXESP database (Sebastián-Gallés et al., 2000) according to the factor positional frequency of the first syllable (more than 1200 vs. less than 550 per million occurrences). All words started with a CV syllable of two letters length. Words were equated on second syllable frequency, word surface frequency, length, number of orthographic neighbors and number of higher frequency orthographic neighbors. Twelve words in each experimental condition had ultimate stress; all other words had penultimate stress. Concerning orthographic redundancy, all the following frequency measures were controlled for: mean frequency of all bigrams, frequency of the initial bigram, frequency of the initial trigram, frequency of the inter-syllabic bigram, mean frequency of all intra-syllabic bigrams (see Table 4). The specific relation between initial syllable-frequency and initial bigram-frequency within the material of Experiment 2 may be highlighted by two example words from the stimulus material: "barril" (barrel) and "fuga" (flight) do not considerably differ in the frequency of the orthographic letter cluster forming their initial syllable (1864 vs. 1878 per million occurrences for the bigrams "*ba*" and "*fu*"), but *"ba-"* is a high-frequency initial syllable (1220 per million occurrences) which is not the case for *"fu-"* (134 per million occurrences). This is because for the majority of all Spanish words starting with the letters "*ba*" these letters form the initial syllable. In contrast, the majority of Spanish words starting with the letters *"fu"* have a different syllable structure, e.g., "fuerte" (strong and "funda" (sheath) the initial syllables of which are *"fuer-"* and *"fun-"*.

<Table 4 about here>

Apparatus and Procedure.

These were the same as in Experiment 1. The stimulus list contained 250 words (72 experimental stimuli and 178 filler items) and 250 nonwords. Nonwords were constructed in the same way as in Experiment 1.

Results and Discussion

Outlier rejection led to a loss of 4.6% of the data in Experiment 2. Four words out of the stimuli of Experiment 2 had to be excluded because of excessive error rates. Analyses revealed significant effects of syllable-frequency on both correct response latencies and error rates (see Table 5). Words were responded to 62 ms slower when starting with a high- than with a low-frequency syllable, F1 (1,45) = 42.37, $p < .0001$, $\eta_p^2 = .485$; F2 (1,66) = 15.40, $p < .0002$, $\eta_p^2 = .189$. Consistently, more errors (11.8% vs. 6.3%) occurred for words with high-frequency initial syllables, F1 (1,45) = 21.83, $p < .0001$, $\eta_p^2 = .327$; F2 (1,66) = 4.34, $p < .04$, $\eta_p^2 = .062$.

<Table 5 about here>

The inhibitory effect of initial syllable-frequency in lexical decision was once again replicated. Importantly, for the first time it could be shown to be independent of the frequency of the letter cluster forming the first syllable, initial bigram-frequency in this case, using only words starting with a two letter CV-syllable. This means that the effect is truly syllabic in nature. It can only be explained as a consequence of syllabic processing, because the frequency of the initial bigram, the relevant alternative orthographic unit, had been controlled for. To complete the contrast of the effects of syllable frequency and letter cluster frequency, it is important to see how initial bigram-frequency influences lexical decision latencies when syllable frequency is controlled for. This was the aim of Experiment 3.

Experiment 3

Method

Participants

Thirty-nine students of the University of La Laguna participated in the experiment.

Stimuli and Design

68 bisyllabic Spanish words were selected from the LEXESP database (Sebastián-Gallés et al., 2000) according to the factor frequency of the initial bigram (more than 3000 vs. less than 1250 per million occurrences). Eight words in the condition of high and six words in the condition of low initial bigram frequency had ultimate stress; all other words had penultimate stress. All words started with a CV syllable of two letters' length. Words were equated on second syllable frequency, word surface frequency, length, number of orthographic neighbors and number of higher frequency orthographic neighbors. Words were also equated on first syllable frequency and on the number of higher frequency syllabic neighbors of the first syllable (see Table 6). Examples from the stimulus material: the initial syllables "*da-*" and "*ti-*" are of comparable frequency in Spanish (864 vs. 856 per million occurrences), but the initial bigram "*ti*" is often included in words with an initial syllable structure other than CV, e.g., "tiempo" (time) with the syllable *"tiem-"* and "tinto" (red wine) with the syllable *"tin-"*. Accordingly, the word "timón" (helm) (initial bigram-frequency: 3805 per million occurrences.) was placed in the high initial bigram-frequency category contrary to the word "dama" (lady) (initial bigram-frequency: 1179 per million occurrences) which entered the low frequency category, because the majority of words starting with the bigram *"da"* have the same initial syllable structure as "dama".

<Table 6 about here>

Apparatus and Procedure

They were the same as in Experiment 1. The stimulus list contained 250 words (62 experimental stimuli and 188 filler items) and 250 nonwords. Nonwords were constructed in the same way as in Experiment 1.

Results and Discussion

Outlier rejection led to a loss of 4.1% of the data of Experiment 3. Four words out of the stimuli of Experiment 3 had to be excluded because of excessive error rates. Analyses revealed significant effects of initial bigram-frequency on both correct response latencies and error rates (see Table 7). Words were responded to 36 ms faster when starting with a high- than with a low-frequency bigram, F1 (1,38) = 15.65, p <.0004, η_p^2 = .292; F2 (1,62) = 4.13, p <.05, η_p^2 = .062. Consistently, more errors (10.3% vs. 16.6%) occurred for words starting with a low- than with a high-frequency bigram, F1 (1,38) = 21.26, p <.0001, η_p^2 = .359; F2 (1,62) = 5.07, p <.03, η_p^2 = .076.

<Table 7 about here>

The interesting outcome of Experiment 3 is that an alternative frequency count of what from a superficial view could be considered the same sublexical unit, the first two letters of a bisyllabic word, produced the opposite effect to that in Experiment 2. Whereas initial syllable-frequency had prolonged response latencies to bisyllabic words starting with a two-letter syllable in Experiment 2, this time the frequency of the initial bigram caused a facilitative effect when syllable-frequency was controlled for. That means there is a perfect contrast for effects of syllable-frequency and letter cluster frequency: When the first two letters can be defined as a syllabic unit and when their frequency is computed accordingly, inhibition of lexical access is the consequence of increasing syllable-frequency. The opposite, a facilitative effect, is obtained for initial letter cluster frequency when the frequency of the first two letters is computed in a purely orthographic manner, not taking into account syllabic structure.

Simulations with the MROM using the data of Experiments 2 and 3

It has been claimed that an interactive activation model of visual word recognition (e.g., Grainger & Jacobs, 1996) might account for the inhibitory effect of syllable frequency on lexical access when implemented with a layer of syllabic representations (see Álvarez et al, 2001; Conrad & Jacobs, 2004). Before going into the details of the possible architecture of such a future model during the General Discussion, it was useful to test the performance of an existing functional version of the Multiple Read-Out Model (MROM, Grainger & Jacobs, 1996) without syllabic representations in a null-model approach (Jacobs et al., 1998) with regard to the empirical effects of Experiments 2 and 3. The MROM can generate a “yes” response in the lexical decision task through two different processes: Either activation of a single word unit (μ) reaches a threshold M corresponding to the identification of the target, or global activation in the lexicon (σ) reaches a threshold $\sum$ corresponding to a “fast guess”.

Because the model does not contain any syllabic representations, we predict that it would fail to simulate the syllable frequency effect in Experiment 2, where letter cluster frequency was controlled for. However, the model might well be capable of reproducing the facilitative bigram frequency effect in Experiment 3, due to activation sent from letter units to word representations in the orthographic lexicon. For words containing a high-frequency bigram, global activation in the orthographic lexicon of the model might increase sufficiently to trigger a quick yes-response of the model via the ∑-criterion of the MROM. Note that the model's behavior with regard to the manipulation of bigram frequency would offer a good prediction of how such a model without syllabic representations would behave regarding manipulation of syllable frequency co-varying with letter cluster frequency.

The model was implemented with a lexicon of 6,242 bisyllabic Spanish words, including bisyllabic entries of the LEXESP database (Sebastián-Gallés et al., 2000) with a frequency of at least 1 per million occurrences. All parameters of excitatory and inhibitory connection weights between different representation units in the model were the same as in Grainger and Jacobs (1996). Given that word length in Experiments 2 and 3 varied between four and six letters, it was necessary to enable the model for the processing of stimuli with different length[4]. The model was presented with a subset of the stimulus material of Experiments 2 and 3. For both experiments, fifty-six words each were selected out of all words that had been used in the respective previous analyses, with the constraint that not only mean word length, but also the exact number of four- five- and six-letter words had to be equated between conditions (see Footnote 4). This selection procedure preserved an optimal match between conditions (according to the manipulation of initial syllable frequency on the one hand and of initial bigram frequency on the other) on variables known to influence the MROM's performance: word frequency, orthographic neighborhood density and number of higher frequency orthographic neighbors (all p-values for t-tests for significant mean differences >0.7).

Each stimulus was processed by the model during thirty cycles and activation values for global activation (σ) and for the most activated single unit in the orthographic lexicon (μ) were recorded. We conducted consecutive t-tests in order to examine if the manipulations of syllable- and bigram frequency significantly affected any of the two activation parameters of the MROM mentioned above at any of the processing cycles of the model. These tests did not reveal any significant results (all p-values >0.2). Note that there was some oscillation due to use of different word lengths in the values of global lexical activation during the first processing cycles, but all curves stabilized after cycle number nine.

For cycles nine to thirty, no single t-test resulted in a p-value less than 0.6. Despite this lack of significant mean differences of activation on single processing cycles, global lexical activation was slightly increased between cycles thirteen to twenty for words with high compared to low initial bigram frequency (see Figure 1). No such modulation of global lexical activation could be observed for the manipulation of syllable frequency, neither seemed any of the two manipulations to affect the activation level of the most activated single word representation in the model's lexicon.

<Figure 1 about here>

This pattern of results is partly compatible with our hypothesis that the σ-process of the MROM might be sensitive to bigram frequency. The possible responses given separately via the two criteria of the model are presented in Figure 2. Whereas the M-threshold for responses via the μ-activation of the model is a fixed value - set at 90% of the asymptotic value of the corresponding mean activation function - the setting of the ∑-threshold is more flexible in order to enable the model to account for task specific effects and to make the probability of a "fast-guess" depend on early processing phases of the stimulus. Depending on the global lexical activation during cycles two to seven, the ∑-threshold of the model can be shifted up- or downwards. Here, we decided to apply a fixed ∑-threshold because of the slightly oscillating σ-activation functions during these cycles, but the threshold was set at a relatively liberal value of 95% of the corresponding asymptotic value, in order to increase the chance of an effect of bigram frequency to arise in the model's ∑-responses. As evident from Figure 2, responses corresponding to the ∑-criterion of the model were somewhat faster for words with high than with low initial bigram frequency, but this effect failed to reach statistical significance, $F(1,54) = 2.68$; $p > 0.1$, $\eta_p^2 = .050$. Analyses revealed no effect at all regarding responses via the ∑-criterion for the manipulation of syllable frequency, $F<1$. Furthermore, no effects were obtained for either of the two manipulations on responses via the M-criterion of the MROM, both $F<1$.

<Figure 2 about here>

Finally, even if the tendency of bigram frequency to speed responses via the ∑-criterion can be considered as modest evidence for the hypothesis that the MROM might account for the empirical effect in Experiment 3, this tendency is attenuated when the responses corresponding to the two different criteria are combined (i.e., always choosing the faster of the two). Even when applying a liberal ∑-criterion, the final output of the MROM only reveals a very small tendency of responses being faster to words with high than with low bigram frequency, $F(1,54) = 1.42$; $p > 0.3$, $\eta_p^2 = .026$. Final responses of the model compared to the data of Experiments 2 and 3 are presented in Figure 3[5].

<Figure 3 about here>

Thus, it appears that the actual MROM is not capable of accounting for an effect of syllable- or bigram frequency in visual word recognition. Whereas the absence of an initial syllable frequency effect – with initial bigram frequency being controlled for - in the simulation data is no surprise, given that the model does not contain syllabic representations, the model's failure to significantly account for the initial bigram frequency effect in Experiment 3 deserves further consideration.

We had hypothesized that such an effect might occur in the model as a function of increasing global lexical activation due to the frequency of initial bigrams in the stimulus words. Note that such an argument is not without problems, because even if the activation of many word representations sharing a high-frequency bigram would certainly lead to an increase in global lexical activation, these word representations would also compete with each other via lateral inhibition. A response via the M-criterion of the MROM could therefore have been delayed or inhibited to the same extend that a response via the ∑-criterion was expected to be speeded by bigram frequency. It is not trivial to predict which of the two processes would prove to be predominant in the model's output. The present simulation data provided no evidence that the μ-process of the MROM is sensitive to bigram frequency, but the observed increase of global lexical activation was not significant either.

In any case, the absence of a significant bigram frequency effect in the simulation data means that the MROM apparently allows for word representations to significantly influence the model's behavior only when these words share more than two letters (in the case of stimuli varying between four and six letters length) with the target (but see Grainger & Jacobs, 1993 for positional letter frequency effects in monosyllabic words).

General Discussion

The experiments of the present study were designed to test for the nature of an effect that has repeatedly been quoted as evidence for automatic syllabic processing during visual word recognition: the syllable-frequency effect. Whether this effect can really be attributed to the processing of syllables or whether it could rather be understood as a by-product of purely orthographic processing is the main question addressed in the present study. The present experimental results provide clear evidence that the syllable-frequency effect in lexical decision occurs independently of bigram troughs or letter cluster frequency.

Experiment 1 showed that the inhibitory effect of initial syllable-frequency remains unaffected by the presence or absence of a bigram trough at the syllabic boundary (Seidenberg, 1987, 1989). Therefore, at least for the Spanish language, it can no longer be argued that an apparent syllabic segmentation could occur as a by-product of or would be facilitated by purely orthographic processing that would use a typically low-frequent bigram at the syllabic boundary as a segmentation device.

Experiment 2 shows that the inhibitory effect of syllable frequency can also be obtained when the frequency of the letter cluster forming the syllable (the first bigram in words starting with a two letter CV-syllable) is controlled for. This important finding provides the missing link in the line of argument in favor of syllabic processing in visual word recognition: Previous studies controlled for the confound of syllable frequency with orthographic redundancy by using only words that did not show the bigram trough pattern at the syllable boundary. Yet, the fact that in most cases a high-frequency syllable is also a high-frequency letter cluster remained a critical point of this approach, because it allowed for an alternative interpretation of these results: it might not be the frequency of syllabic units but the frequency of letter clusters, which can be understood as purely orthographical without any reference to syllabic units, that might have triggered the empirical effects attributed to syllable frequency.

The considerable size (62 ms) of the syllable-frequency effect when bigram-frequency was controlled for is perfectly in line with the outcome of Experiment 3 where a facilitative effect of initial bigram-frequency was obtained when syllable-frequency was held constant.

The main contribution of the present results to a better understanding of polysyllabic word processing lies in the finding that one and the same sublexical unit seems to be functional in opposite ways depending on how it is defined and how, in consequence, its frequency is computed. The frequency of a word's first two letters (the first syllable) had an inhibitory effect in Experiment 2, where the manipulated variable syllable-frequency was computed taking into account the frequency of all bisyllabic Spanish words starting with the same two letters as a syllable. In contrast, in Experiment 3, the frequency of the first two letters was computed referring to all bisyllabic words starting with the same two letters regardless of whether they formed the initial syllable or not. This time, response latencies to words decreased with increasing frequency of the first bigram. These findings suggest that syllabic units and orthographic letter clusters affect polysyllabic word reading at different processing levels.

It appears that the activation of lexical candidates competing with each other for identification during polysyllabic word recognition is strongly mediated by syllabic units whereas the frequency of orthographically defined units as bigrams rather seems to enhance early prelexical processing. Bigram frequency might facilitate prelexical orthographic processing in general (see the outcome of the multiple regression analyses of the data of Experiment 1; see Massaro & Cohen, 1994, for a facilitative bigram-frequency effect in a letter search task; see also Hauk et al., 2006), but the fact that initial bigrams in Experiment 3 always formed the initial syllable of target words leaves open the possibility that this empirical effect could relate to syllabic processing with bigram frequency facilitating the syllabic parsing of orthographically presented words.

This contrast between effects of syllable-frequency and letter cluster frequency presents a serious challenge for any model of visual word recognition that is not sensitive to syllabic structure. In our view, a model that aims to account for this contradictory role of the same sublexical unit needs some implemented definitions of how such a sublexical unit can be characterized (syllable and/or bigram) according to which it will be assigned a specific role at different processing stages. Parallel distributed models (e.g., Seidenberg & McClelland, 1989; Plaut, McClelland, Seidenberg, & Patterson, 1996), in particular, would face some serious difficulties with regard to the present results. In the first place, these models do not comprise a mechanism of lateral inhibition which could account for the competition between candidate words. Instead, they would always predict facilitative effects for the frequency of sublexical units. The inhibitory syllable frequency effect would most probably fall beyond their scope. Furthermore, it is unclear how they could possibly account for the two different effects of the first two letters' frequencies (syllable-frequency and bigram-frequency) without postulating the involvement of different representational units.

With regard to localist connectionist models, simulations run with the MROM (Grainger & Jacobs, 1996), a model containing a mechanism of lateral inhibition between candidate words, have shown that this model cannot simulate the inhibitory syllable frequency effect without containing syllabic representations. Regarding the facilitative effect of bigram frequency in Experiment 3, the architecture of the MROM comprising connections between letter and whole word representations would in principle allow for such an effect of purely orthographic letter cluster frequency to arise in the simulations. Word processing in the model seemed to be sensitive to bigram frequency to some extent: global lexical activation within the model was increased for words with high frequency bigrams during processing cycles thirteen to twenty. But these differences did not reach statistical significance.

Clearly, more empirical work is necessary to examine whether such an empirical effect is independent from syllabic structure. As regards the relatively low degree of sensitivity of the MROM (without syllabic representations) to bigram frequency, this problem might possibly be resolved by the adjustment of parameter weights- provided that the effect would prove to be purely orthographic in nature - without any relation to syllabic units.

On the other hand, a localist connectionist model containing several different representation layers – one of them for syllabic units - could in theory deal with such opposite effects of the frequency of the same first two letters, because activation would be sent out from the first two letter units in different ways: letter representations would directly activate whole word representations containing the target letters. They would also activate syllabic representations, which would subsequently send activation to the word level. The possible architecture of such an interactive activation model of polysyllabic visual word recognition is sketched in Figure 4.

<Figure 4 about here>

The model contains both an orthographic and a phonological lexicon and activation spreads from letter representations via grapheme, phoneme and syllabic representations on to whole word representations in the two lexica. A "yes" response in lexical decision would occur when an activation threshold for a single word representation (corresponding to identification of the target) or for global lexical activation (corresponding to a "fast-guess") is reached in one of the two lexica of the model (see Grainger & Jacobs, 1996; Jacobs, Rey, Ziegler, & Grainger, 1998). Syllabic representations are located in the phonological route of the model mediating the activation of phonological word representations (see Mathey, et al., 2006, for a similar proposal). Syllables are generally seen as phonological units and there is evidence for a phonological nature of syllabic processing also in visual word recognition (Álvarez et al., 2004). The fact that within our data syllabic effects were shown to be independent from orthographic redundancy is additional support for this view.

The inhibitory effect of initial syllable frequency would occur in the model, because an initial phonological syllable's representations would activate a cohort of syllabic neighbors' representations in the phonological lexicon that would interfere with the processing of the target by the mechanism of lateral inhibition. The size of this cohort and its inhibitory potential would increase with syllable frequency explaining the processing delay for words with high syllable frequency. We had argued that the failure of the MROM to significantly reproduce an effect of bigram frequency is probably due to the fact that word representations sharing only a small amount of letters with the target do not become sufficiently activated. Regarding syllabic processing in the model, this problem might be resolved by strengthening the connection weights between initial syllabic units and the phonological lexicon (see Álvarez, Carreiras, & de Vega, 2000, for differential effects of first and second syllable frequency). Furthermore, a phonological syllable always represents 50% of a bisyllabic phonological word form. In contrast to bigrams, which are not represented as specific multi-letter units in the model, syllabic units would activate a well-defined cohort of candidate representations – the syllabic neighborhood. Syllable-mediated activation over the phonological lexicon would be less widespread than activation over the orthographic lexicon coming from the representations of all letters of the target. This might ensure sufficient sensitivity of the model to syllable frequency with syllabic neighbors' representations getting sufficiently activated to compete with the target for identification.

For the present study we only used words of relatively low word frequency, but the model makes the prediction that syllabic processing in visual word recognition would become less important with increasing word frequency, because fast access to high frequency word representations would be possible via the orthographic layers of the model, which do not contain syllabic representations. Phonological processing in the model always requires the previous activation of orthographic representation units and will therefore always be somewhat delayed relative to orthographic processing. This is in line with the finding that syllable frequency effects are always more pronounced for low frequency than for high frequency words (Perea & Carreiras, 1998; Conrad & Jacobs, 2004). It might be argued that an increasing cohort of co-activated candidate representations sharing a phonological syllable would also lead to an increase in global lexical activation and that responses corresponding to a fast guess could foil or contrast the hypothesized delay of identification for high syllable frequency words in a model with a multiple-read-out procedure. But note that responses according to the ∑-criterion of the MROM are strongly dependent on early processing phases of the model, because ∑-thresholds are adjusted as a function of global lexical activation values during the first seven cycles of the model (see Grainger & Jacobs, 1996). As outlined above, the processing of phonological syllable neighbors within the model would take place at a relative late processing stage and fast-guess responses to high syllable-frequency words might therefore not play an important role in the model's output.

Now, even when assuming the existence of automatic syllabic processing in visual word recognition, one crucial question remains to be resolved: how would the reading system achieve a syllabic segmentation of the orthographic input? We could show in Experiment 1 that the presence or absence of a bigram trough at the syllable boundary of Spanish words does not modulate syllabic processing as reflected by the syllable frequency effect. Still, orthographic redundancy might play a role for syllabic processing in that syllables become more salient when being formed of letter clusters with a high orthographic frequency (see Mathey et al., 2006). Within the model we propose, a high frequency bigram's letter representations would receive more feedback activation from the orthographic lexicon than those representing a low- frequency bigram. In consequence, they would more efficiently activate a corresponding syllabic unit at the layer of phonological syllables. Therefore, the facilitative bigram frequency in Experiment 3 could arise in the model, because high frequency initial bigrams corresponding to a word's initial syllable would facilitate the syllabic parsing process allowing for a faster access to a word's representation in the phonological lexicon (see Conrad et al., 2006, for a discussion on why syllabification is a necessary prerequisite for the processing of phonological word forms).

Two recent ERP-studies provide additional evidence for this line of argument regarding the interplay between orthographic and phonological processing during the time course of visual word recognition: These studies reporting syllable frequency effects on ERP-waves during lexical decision consistently obtained significant effects of syllable-frequency on two distant time windows. Both Barber et al. (2004) and Hutzler et al. (2004a) obtained increased negativity for words with high relative to low initial syllable frequency around the N400 component of the ERP-signal. This relatively late effect was interpreted as to reflect competition between syllabic neighbors at the level of whole word representations (see Perea & Carreiras, 1998; see Holcomb, Grainger, & O'Rourke, 2002, for an N400 effect for words with many orthographic neighbors, see also Goslin, Grainger, & Holcomb, 2006). But high syllable frequency also produced an early increase of negativity in the ERP-signal between 150-300 ms in the study of Barber et al (2004) and between 190-280 ms in Hutzler et al's (2004a) experiment (see Carreiras, Vergara, & Barber, 2005, for a P200 effect of syllabic congruency for words presented in colors that matched or mismatched syllabic structure). The onset of these early syllable frequency effects was prior to typical markers of lexical access as the effects of word frequency in Barber et al. (2004) or of lexicality in Hutzler et al. (2004a), which did not start before 350 ms. Therefore, these effects seem to arise during prelexical processing. Initial bigram frequency has been shown to influence the ERP-signal as early as 100 ms after stimulus presentation in visual word recognition (Hauk et al., 2006). Note that there was no control for the confound between syllable- and letter cluster frequency in the studies of Barber et al. (2004) and Hutzler et al. (2004a). The early effects of syllable frequency they obtained might reflect the moment when phonological syllables become salient or are identified within the orthographic input and letter cluster frequency might play a crucial role during this process.

In general, given the opposite effects of syllable frequency and bigram frequency and the independence of the syllable frequency effect from bigram troughs at the syllable boundary, our data make a stronger case for the importance of the syllable in visual word recognition with regard to the relation between orthographic redundancy and syllabic processing than recent studies in French (Mathey et al., 2006; Doignon & Zagar, 2005). Apart from some problems with the material used in these studies, these differences might result from specific properties of the different languages at hand. Whereas the French language is characterized by a considerable degree of inconsistency in particular in the mapping form phonemes to graphemes (see Ziegler, Stone, & Jacobs, 1996), the mutual mapping between phonemes and graphemes in Spanish is very consistent and this has important consequences for the transparency of syllabification in Spanish orthographic word forms. An analysis of syllabification for all bisyllabic words in the LEXESP database (Sebastián-Gallés et al., 2000) revealed that correct syllabic parsing for all Spanish orthographic word forms is possible following some very simple principles of segmentation (Conrad, Carreiras, & Jacobs, in revision): the Spanish language allows for a very restricted number of consonant clusters within one syllable. The maximum number of consonants at the syllabic onset is two and generally only one consonant is licensed as a syllabic offset[6]. Syllabification in Spanish is perfectly described by the principles of maximum syllabic onset and of a maximum sonority contrast at the syllable boundary: whenever one single consonant grapheme occurs between two vowels in a Spanish word, this consonant forms the onset of a syllable. A pattern of three consonant graphemes is always parsed as follows: the first segment is a syllabic offset and the two subsequent ones form a syllabic onset. The only ambiguity in terms of how to syllabically parse a given number of consonant graphemes between two vowels is given when two consonant graphemes occur together. But even in this case, correct syllabification can always be achieved without the involvement of lexical knowledge, because any given combination of two specific consonant graphemes can only occur either within a Spanish syllable or has to be separated by a syllabic boundary. It never occurs that both possibilities exist for the same two consonants[7].

The regularity of syllabification in Spanish and the simplicity of the principles by which syllable boundaries can be identified within the Spanish orthography make it plausible that Spanish readers would implicitly make use of such principles for the segmentation of polysyllabic word forms. This would mean that they would not necessarily need additional information from orthographic redundancy in order to identify and process a word's phonological syllables. A model of visual word recognition might therefore be implemented with a syllabic parsing mechanism that is sensitive to these principles.

Hutzler et al. (2004b) as well as Perry, Ziegler and Zorzi (2007) have shown how a computational model can learn such "rules" when presented with an input characterized by specific regularities. In the model presented in Figure 4, this syllabic parser would perform a syllabic segmentation of the target and determine the activation of phonological syllables' representations. In addition, these phonological syllable representations would receive activation from their corresponding letter representations via the principles of interactive activation, but clearly, orthographic redundancy would not be the necessary base for syllabic processing to occur. Using such a syllabic parser in languages with a transparent orthography and regular syllabification and suppressing its activity in languages with less transparent syllabic structure might enable the model to account for language specific differences in syllabic processing. Suppressing the syllabic parser and its "rule-based" unambiguous syllabic segmentation would involve an increased probability for orthographic redundancy to influence the activation of syllabic representations. Stressing the competition between different syllabic representational units based on activation from lower level representational units might assure a better account for syllabic processing in languages with less transparent syllabic structure.

In any case, our results show that the recognition of polysyllabic words in visual word recognition cannot be fully understood without taking into account the involvement of syllabic processing. Adding to the already vast literature showing phonological influences on visual word recognition (e.g., Carreiras, Ferrand, Grainger, & Perea, 2005; Ferrand & Grainger, 1992; Frost, 1998; Lukatela & Turvey, 1994; Grainger & Ferrand, 1994; Lukatela, Eaton, Lee, Carello, & Turvey, 2002; Lukatela, Frost, & Turvey, 1998; Perfetti & Bell, 1991; Pollatsek, Perea & Carreiras, 2005; Pollatsek, Lesch, Morris, & Rayner, 1992; Van Orden, 1987; Van Orden; Johnston, & Hale, 1988), the present findings suggest that during visual word recognition, phonological rather than orthographic processing involves the emergence of clusters at an intermediate level between basic sublexical units (letters, graphemes and phonemes) and whole word forms. These phonological clusters – a word's syllables – seem to have an important role for the activation of word candidates.

Notes

[1] The effect of syllable boundaries on illusory conjunctions was completely absent for words starting with a three-letter syllable in Experiment 2 of Doignon and Zagar (2005), but we believe that this specific result should be handled carefully. Internal syllabic structure (e.g., CCV vs. CVC) of words was not controlled for within the material of this experiment, initial syllables with a consonant orthographic offset (e.g., dan_ser) occurring more often in the condition where bigram troughs did not coincide with syllable boundaries. This might be important, because consonants forming the orthographic offset of French syllables are often not pronounced or become part of a nasal vowel phoneme, which might present a problem fort the mapping between phonological syllables and their orthographic representations. Furthermore, some words (e.g., piano, ruiné), which might be interpreted as trisyllabic strongly contributed to the specific empirical pattern of results -. If, e.g., the word “ruiné” would be parsed as “ru-i-né” instead of “rui-né”, this would make the low-frequency second bigram “ui” (characterized as intra-syllabic in this experiment) an inter-syllabic bigram coinciding with a syllabic boundary, undermining the experimental manipulation.

[2] Note that the size of the syllable frequency manipulation in Experiment 2 of Mathey et al. (2006) was much stronger in the case of high- than of low-frequency orthographic letter clusters; a relatively high number of syllabic neighbors was only present in the condition of high orthographic frequency/high syllable frequency. This represents a problem for the interpretation of the observed interaction between the effects of syllable frequency and letter cluster frequency as well as for an interpretation of the absence of a significant letter cluster frequency effect in this experiment of Mathey et al. (2006).

[3] For all experiments, stimulus characteristics are reported only for words that actually entered the analyses of the experimental data.

[4] Range of word length in the lexicon was three to eight letters. For all words with less than eight letters, the respective (missing) letter positions were filled with blanks. Blanks in specific letter positions did not activate word representations, but inhibited the representations of words having a letter in that specific position. E.g., when presented with a four letter target, all five letter words’ representations in the model’s lexicon received inhibition coming from the blank in position five of the target. Note that this model is not able to correctly account for a word length effect in visual word recognition – five and six letter words always receiving more summed activation from their corresponding letter representations than four letter words. But for the present purpose, the simulation of syllable and bigram frequency effects, this should not be a problem as long as word length remains closely controlled for within the stimulus material. Implementing the model with differential letter-to-word-unit activation weights for different stimulus lengths (which would be a possible solution to the paradoxical behaviour of such a model regarding the issue of word length effects) might in turn have resulted in bigram- or syllable frequency being less effective in longer compared to shorter words.

[5] The empirical data is based on the same words that were used for the simulations. Both the effects of syllable frequency (79ms) and of bigram frequency (52ms) were statistically significant, $F(1,54) = 14.96$; $p<0.0004$; $F(1,54) = 4.06$; $p<0.05$

[6] The only exceptions from these rules are syllabic offsets including one consonant plus the consonant “s” which is added to the syllabic offset because it cannot be combined within the letter “t” at the onset of a subsequent syllable. Example words are “instante” (moment) or “obstar” (to hinder).

[7] E.g., “bl” or “br” can only be syllabic onsets like in the words “hablar”, or “abrir” whereas “st” or “rt” will always include a syllable boundary like in words as “hasta” or “huerto”.

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Table Captions

Table 1

Characteristics of Words used in Experiment 1
Means, Ranges and Standard Deviations (SD) for
- Independent Variables: Difference (DIFF) between the mean Frequency of all intra-syllabic Bigrams (BF IntraSyll) and the frequency of the inter-syllabic Bigram (BF Bound); positional Frequency of the first Syllable (SF1)
- Variables related to the Bigram Trough Manipulation: Frequency of the least- (BF Min) and of the highest-frequent Bigram (BF Max) in a Word
- Variables correlated with initial Syllable Frequency (SF1): positional Frequency of the first two (FL2) and three (FL3) Letters and positional Frequency of the Letter Cluster representing the first Syllable (FLSyll)
- Control Variables: Whole Word mean Bigram Frequency (BF Word), Word Frequency (WF), Familiarity (Fam), Concreteness (Concr), Word Length (L), Density of orthographic Neighborhood (N), Number of higher Frequency orthographic Neighbors (HFN), positional Frequency of the second Syllable (SF2)
Probability Values are given for Mean Differences across the different Cells of the two experimental Factors Syllable Frequency (p(SF)) and relative Bigram Frequency at the Syllable Boundary (p(trough)).

	Bigram Trough at the Syllable Boundary							No Bigram Trough at the Syllable Boundary							
	High SF1			Low SF1				High SF1			Low SF1				
	Mean	SD	Range	Mean	SD	Range		Mean	SD	Range	Mean	SD	Range	p (SF)	p (trough)
BF_IntraSyll	2417	1186	1216-5872	2592	863	1160-5010		1760	517	1048-3393	1476	910	421-3850	p>.85	p>.0001
BF_Bound	553	519	15-2268	558	391	7-1445		3294	918	2208-5562	3492	1451	1013-5849	p>.89	p<.0001
DIFF	1864	878	1035-4187	2034	640	1093-3565	-	-1534	980	-3475- -273	-2016	1408	-4685- -229	p>.85	p<.0001
BF Min	543	513	15-2245	419	312	7-1224		1079	460	55-2295	774	743	16-3363	p<.06	p<.0001
BF Max	3745	2355	1780-13111	4584	2444	1377-13111		3562	1257	2208-7834	3609	1492	1302-6268	p>.25	p>.13
BF Word	1875	936	999-4971	2017	708	776-4119		2167	489	1473-3502	2010	891	642-4148	p>.94	p>.38
SF1	1101	644	607-2728	149	89	12-298		1291	923	621-4175	122	81	6-268	p<.0001	p>.52
FL2	2087	1226	974-4205	1276	1005	31-3821		1896	1029	974-4398	1059	940	15-3821	p<.0003	p>.40
FL3	380	506	2-1609	146	258	4-1054		473	440	13-1428	199	299	4-1054	p<.002	p>.34
FLSyll	1740	1266	692-4205	870	923	28-2711		1666	1056	755-4398	581	513	7-1253	p<.0001	p>.44
WF	14.58	16.90	1-71	13.03	12.90	1-46		14.34	14.47	2-55	11.50	13.19	2-57	p>.45	p>.76
Fam*	4.80	1.12	2.57-6.45	5.13	0.91	3.50-6.70		5.03	1.05	2.75-6.35	5.45	0.91	3.38-6.73	p>.07	p>.20
Concr*	4.72	1.00	3.00-6.88	4.46	1.10	2.88-6.47		4.44	1.18	2.50-6.39	5.32	0.96	2.75-6.74	p>.16	p>.17
L	4.61	0.72	4-6	4.62	0.64	4-6		4.83	0.70	4-6	4.72	0.54	4-6	p>.66	p>.21
N	7.83	5.77	0-23	8.08	4.77	0-18		8.46	6.52	0-25	7.16	5.48	0-19	p>.64	p>.85
HFN	2.43	2.81	0-10	2.46	2.20	0-7		2.83	2.46	0-8	2.40	2.22	0-8	p>.67	p>.73
SF2	2393	2207	11-8035	3033	2582	8-8035		2677	3013	37-10867	2794	3066	14-10867	p>.49	p>.99

* These variables had not explicitly been controlled for when selecting the stimulus material of Experiments 1-3. Mean rating values of familiarity and concreteness – ranging from 1 (“not familiar/concrete at all”) to 7 (“very familiar/concrete”) - are taken from the BuscaPalabras database (Davis & Perea, 2005) or - if not provided in this database - have been collected from Spanish speakers that had not participated in Experiments 1-3.

Note: Frequency counts are given per million occurrences, taken from the LEXESP database (Sebastián-Gallés et al., 2000)

Table 2

Mean Reaction Times (RT; in Milliseconds), Standard Deviation of Reaction Times (Std. Dev. in Milliseconds) and Percentage of Errors for Words in Experiment 1

	Bigram Trough at the Syllable Boundary					
	Yes			No		
Syllable Frequency	RT	Std. Dev.	% error	RT	Std. Dev.	% error
High	815	140	10.7	796	137	12.0
Low	773	130	7.8	754	114	7.3

Table 3

Pearson Product-Moment (r) and Partial Correlations (pr) between Response Latencies (RT) and seven Predictors for Words used in Experiment 1. The Predictors are: Log (10) of Word Frequency (Log WF), Log (10) of Token Frequency of the first (Log SF1) and second (Log SF2) Syllable, the Bigram at the Syllable Boundary (Log BF Bound), the mean Frequency of all intra-syllabic Bigrams (Log IntraSyll), the Frequency of the least-frequent (Log BF Min) and the highest-frequent Bigram (Log BF Max).

	r	pr
Log WF	-.500	-.510**
Log SF1	.192	.284**
Log SF2	-.053	-.016
Log BF Bound	-.248	.096
Log BF IntraSyll	-.015	.187
Log BF Min	-.200	-.224*
Log BF Max	-.270	-.251*

* p<.05

** p<.01

Table 4

Characteristics for Words used in Experiment 2

Means and Ranges for the independent Variable: Positional Frequency of the first Syllable (SF1). Means and Ranges for Control Variables: Positional Frequency of the first two (FL2), three (FL3), and four (FL4) Letters, mean Frequency of all intra-syllabic Bigrams (BF IntraSyll), Frequency of the inter-syllabic Bigram (BF Bound), whole Word mean Bigram Frequency (BF Word), Word Frequency (WF), Familiarity (Fam), Concreteness (Concr), Word Length (L), Density of orthographic Neighborhood (N), Number of higher Frequency orthographic Neighbors (HFN), positional Frequency of the second Syllable (SF2). Probability Values (p) are given for Mean Differences across the different Cells of the Factor Syllable Frequency.

	First Syllable Frequency						
	High			Low			
	Mean	SD	Range	Mean	SD	Range	p
SF1	1796	551	1220-2742	354	133	133 526	
FL2	2225	550	1586-3017	2242	694	1265-3084	p>.90
FL3	156	199	7-875	109	259	6-1564	p>.40
FL4	39	57	2-182	28	25	3-118	p>.30
FLSyll	2225	550	1586-3017	2223	703	1265-3084	p>.99
BF Word	1908	840	678-3871	1696	793	584-4215	p>.28
BF_IntraSyll	1703	624	801-3318	1733	735	763-3701	p>.85
BF_Bound	2606	3051	36-10690	1705	1952	13-10690	p>.14
DIFF	-903	3192	-9751-2758	28	1991	-8633-3185	p>.14
WF	12.73	12.18	2-46	12.39	9.32	2-42	p>.89
Fam	4.93	1.11	2.63-6.63	5.06	1.00	2.75-6.46	p>.62
Concr	4.72	1.28	1.75-6.88	4.91	1.23	2.75-6.88	p>.54
L	4.72	0.63	4-6	4.67	0.72	4-6	p>.75
N	9.84	7.72	1-25	8.67	7.94	0-28	p>.53
HFN	2.28	2.50	0-9	1.83	2.47	0-9	p>.46
SF2	1619	2717	6-10867	1316	2147	3-8035	p>.60

Note: Frequency counts are given per million occurrences, taken from the LEXESP database (Sebastián-Gallés et al., 2000)

Table 5

Mean Reaction Times (RT; in Milliseconds), Standard Deviation of Reaction Times (Std. Dev. in Milliseconds) and Percentage of Errors for Words in Experiment 2.

Syllable Frequency					
High			Low		
RT	Std. Dev.	% error	RT	Std. Dev.	% error
794	139	11.8	732	107	6.3

Table 6

Characteristics for Words used in Experiment 3

Means and Ranges for the independent Variable: Positional Frequency of the first Bigram (FL2). Means and Ranges for Control Variables: Mean Frequency of the remaining Bigrams (BF2-5), Positional (Word Ending) Frequency of the remaining Letter Cluster (FL3-6), positional Frequency of the first Syllable (SF1), Number of higher Frequency syllabic Neighbors of the first Syllable (HFSN1), Word Frequency (WF), Familiarity (Fam), Concreteness (Concr), Word Length (L), Density of orthographic Neighborhood (N), Number of higher Frequency orthographic Neighbors (HFN), and positional Frequency of the second Syllable (SF2). Probability Values (p) are given for Mean Differences across the different Cells of the Factor Initial Bigram Frequency.

	Initial Bigram Frequency						
	High					Low	
	Mean	SD	Range	Mean	SD	Range	p
FL2	4161	967	3084-5988	1016	247	488-1222	
BF 2-5	1574	1239	296-4931	1695	911	228-3716	p>.65
FL 3-6	3093	3926	55-13384	2196	2551	2-10867	p>.27
SF1	781	236	358-1102	828	195	411-1058	p>.38
HFSN1	15.45	10.40	2-42	15.56	8.81	3-35	p>.96
WF	13.79	13.28	1-47	12.16	13.80	2-55	p>.62
Fam	4.98	0.99	2.63-6.39	4.76	1.19	2.88-6.61	p>.43
Concr	5.08	1.16	2.63-6.88	4.86	1.00	2.75-6.54	p>.41
L	4.45	0.62	4-6	4.44	0.56	4-6	p>.94
N	10.90	5.43	0-21	10.32	7.30	0-25	p>.71
HFN	2.87	2.33	0-8	3.09	3.01	0-10	p>.74
SF2	2724	3416	55-10867	2115	2567	2-10867	p>.41

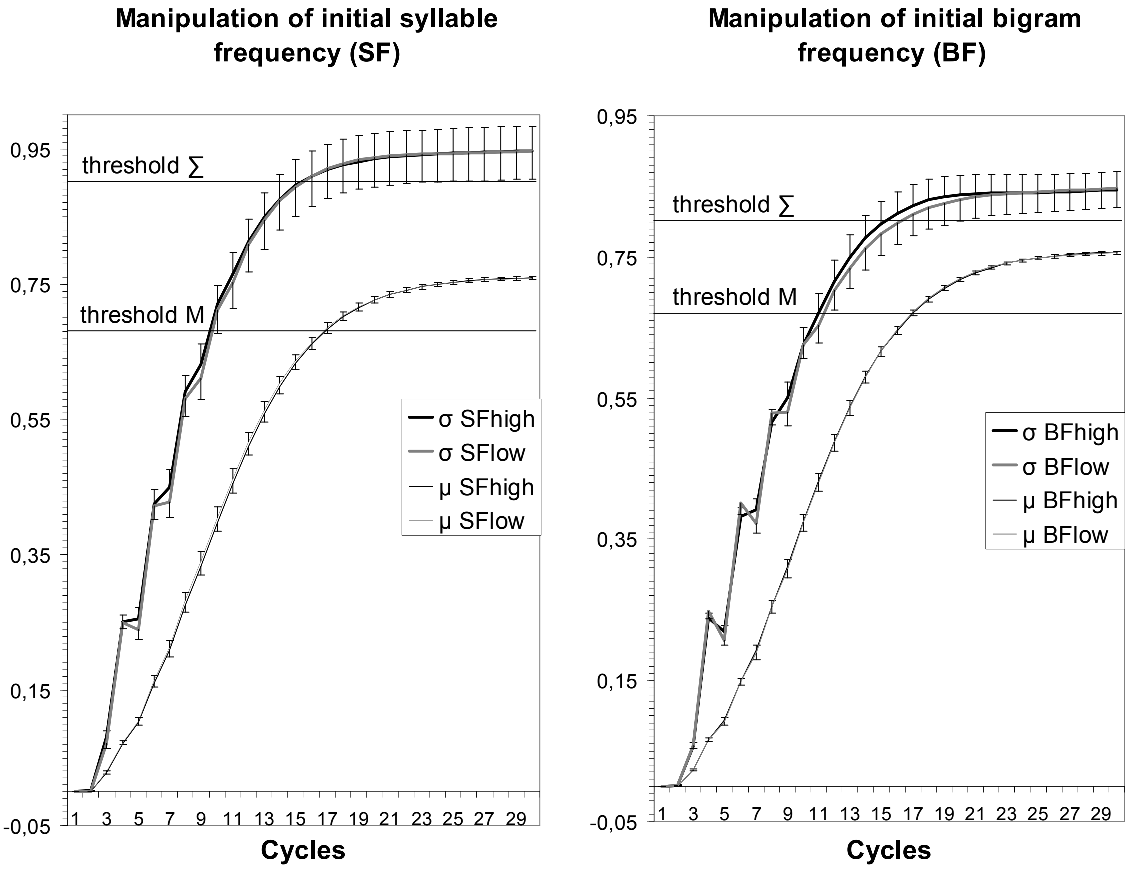
Note: Frequency counts are given per million occurrences, taken from the LEXESP database (Sebastián-Gallés et al., 2000)

Table 7

Mean Reaction Times (RT; in Milliseconds), Standard Deviation of Reaction Times (Std. Dev. in Milliseconds) and Percentage of Errors for Words in Experiment 3.

Bigram Frequency					
High			Low		
RT	Std. Dev.	% error	RT	Std. Dev.	% error
766	104	10.3	802	110	16.6

Figure Captions


Manipulation of initial syllable frequency (SF)

Manipulation of initial bigram frequency (BF)

Figure 1

Mean μ and σ activation functions in the MROM according to the manipulations of initial syllable frequency and initial bigram frequency for words in Experiments 2 and 3

Note: Error bars are giving standard errors of means.

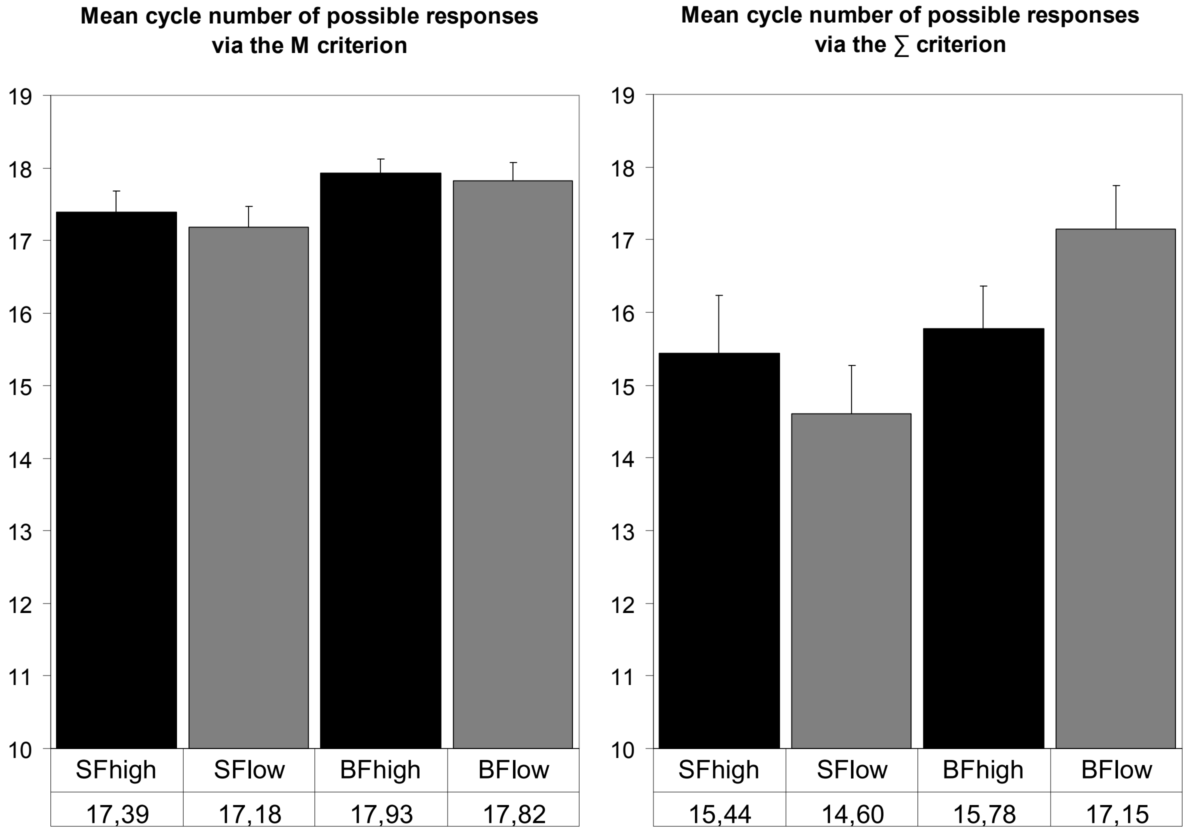


Figure 2

Mean cycle numbers of responses as occurring separately by the two response mechanisms of the MROM according to the manipulations of initial syllable frequency (SF) and initial bigram frequency (BF) for words in Experiments 2 and 3

Note: Error bars are giving standard errors of means.

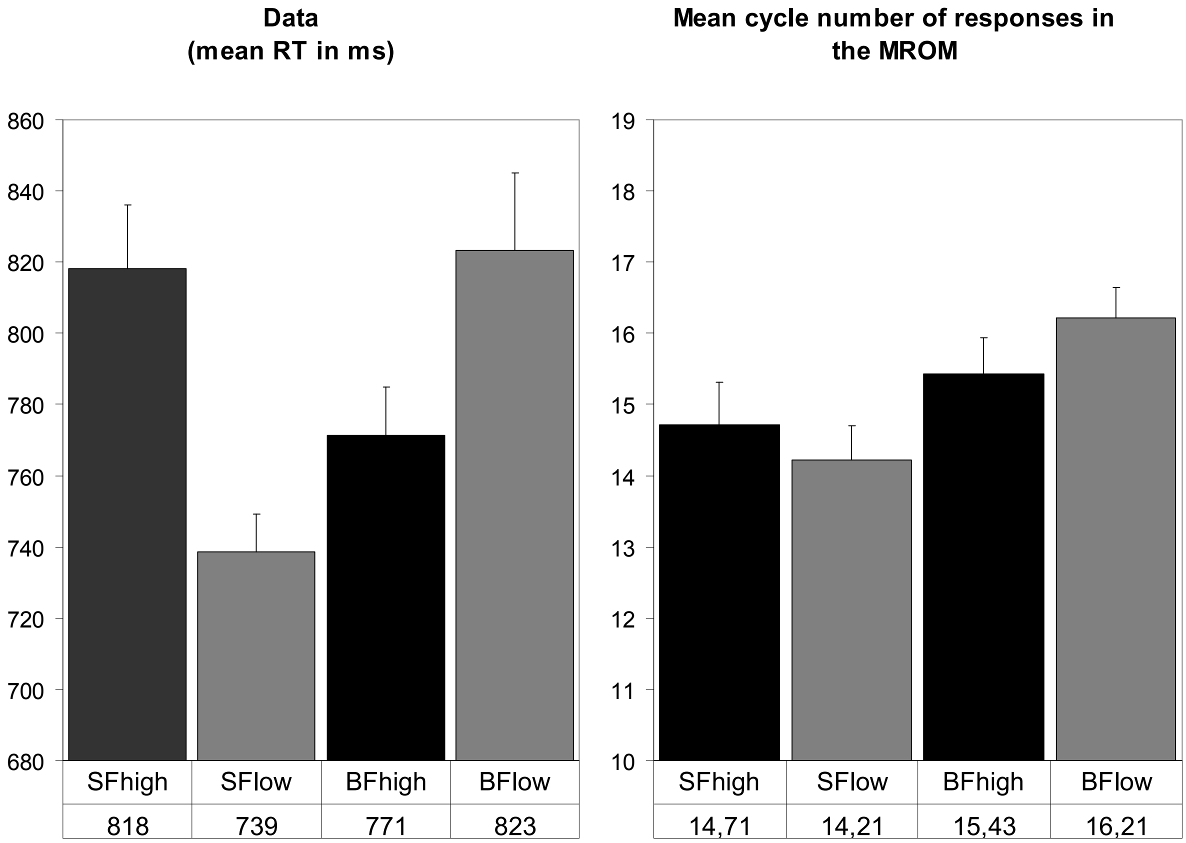


Figure 3

Comparison of the MROM’s final output with the experimental data of Experiments 2 and 3

Note: Error bars are giving standard errors of means.

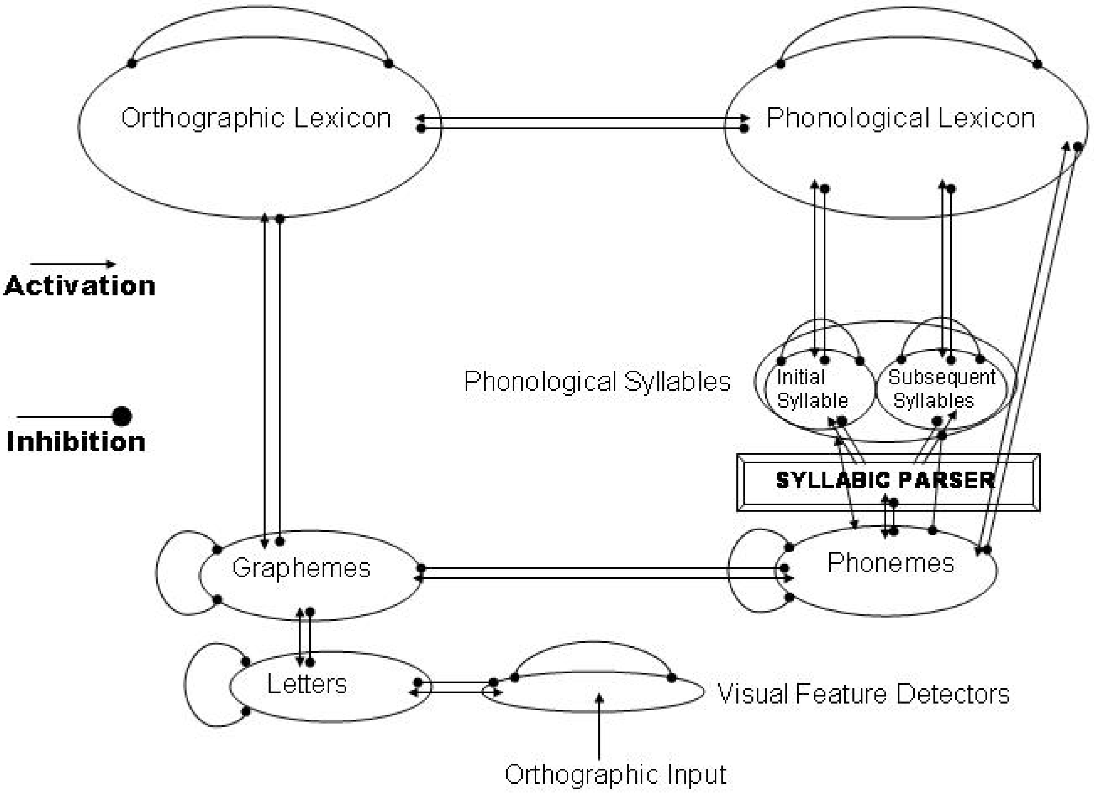


Figure 4

The possible Architecture of an Interactive Activation Model of polysyllabic visual Word Recognition

Appendices

Appendix A

Word Stimuli used in Experiment 1; corresponding mean correct Response Latencies (Mean RT) and Percentage of Errors (%Err)

Words with a Bigram Trough at the Syllable Boundary

High Frequency of the first Syllable			Low Frequency of the first Syllable		
	Mean RT	%Err		Mean RT	%Err
ansia	919	25.58	asma	880	9.52
desliz	950	20.93	brava	830	11.90
forja	896	16.67	bruma	826	8.89
hebra	979	23.81	bruta	712	4.35
letal	837	4.55	buda	825	27.27
lila	778	10.87	cheque	830	6.82
litro	748	2.17	choque	799	2.27
lujo	678	0.00	duelo	714	4.44
mulo	852	16.28	foto	686	6.67
muro	780	6.82	frita	794	9.09
musa	786	9.09	furor	795	4.35
plaga	805	4.44	giro	742	0.00
plagio	1015	11.11	grito	664	2.22
proa	947	30.43	gula	898	30.00
progre	1173	92.86	humor	630	0.00
puma	715	4.55	kilo	746	2.17
quema	775	4.65	manga	846	2.27
quieta	854	0.00	nube	700	2.17
rojo	665	0.00	nudo	762	2.17
rota	777	4.44	nula	817	9.52
sede	934	30.23	nulo	844	13.95
suma	760	6.52	ruda	896	26.67
trapo	779	6.52	rumor	727	4.65
vate	846	83.72	rural	797	2.33
veda	833	75.56	salva	840	12.50
velo	792	8.89	water	936	67.50
veto	905	65.12	zumo	688	0.00

Words without a Bigram Trough at the Syllable Boundary

High Frequency of the first Syllable			Low Frequency of the first Syllable		
	Mean RT	%Err		Mean RT	%Err
antro	1084	34.09	asta	1018	67.44
credo	942	16.28	breva	982	25.00
crema	706	0.00	chelo	930	67.44
fino	751	10.87	clero	801	6.82
heno	951	59.52	fobia	727	2.22
hombro	703	6.67	foca	662	4.35
honor	732	4.35	foco	717	0.00
horror	725	0.00	folio	758	2.17
lacia	911	73.81	foro	728	13.33
lana	680	2.22	forro	773	4.65
liso	666	0.00	foso	774	21.43
malla	995	16.67	freno	677	8.89
manual	741	2.17	fresa	705	4.44
meca	972	45.24	genial	700	6.52
nasa	881	22.22	genio	676	4.35
noble	696	4.35	goce	904	31.43
plana	741	15.56	gorro	663	0.00
plano	675	2.33	junio	728	2.17
prosa	904	6.67	manta	787	2.22
pueril	958	47.73	piano	660	4.35
recia	1074	34.09	plena	716	13.33
roce	805	8.89	tinta	658	0.00
socia	894	40.00	vocal	719	0.00
tambor	768	2.22	yegua	955	4.88
vaca	666	2.17	yema	858	9.30
valla	877	7.50	yeso	762	6.82
vano	845	11.11	yodo	963	14.63

Appendix B

Word Stimuli used in Experiment 2; corresponding mean correct Response Latencies (Mean RT) and Percentage of Errors (%Err)

High Frequency of the first Syllable			Low Frequency of the first Syllable		
	Mean RT	%Err		Mean RT	%Err
baba	826	2.17	ciclo	727	2.27
babor	1058	58.14	ciclón	762	2.50
bala	884	6.82	cifra	757	2.27
ballet	791	21.43	cima	740	0.00
balón	715	13.04	cita	690	0.00
banal	954	56.82	doblez	871	17.39
barra	718	6.67	dote	822	31.71
barril	779	2.33	dócil	796	4.76
barro	737	0.00	dólar	739	4.76
bata	773	0.00	fuga	684	4.55
mecha	890	0.00	fugaz	738	2.22
mechón	788	6.82	furia	715	2.22
mella	1008	62.22	furor	771	4.44
melón	714	2.22	fusil	731	6.82
mesón	870	9.30	nube	681	2.22
meta	718	4.44	nuca	805	16.28
metal	708	2.17	nudo	752	2.22
metro	720	0.00	pico	696	6.52
nasa	895	21.74	pila	766	0.00
nasal	744	2.17	pilar	806	2.63
natal	777	11.11	pino	663	6.98
nato	961	42.22	pipa	726	0.00
naval	816	4.55	pito	752	14.63
nave	780	2.17	piña	633	2.17
nazi	905	30.95	quicio	823	42.11
nácar	921	23.81	tabla	724	2.22
sabor	663	0.00	tablón	699	0.00
saco	748	2.27	tabú	764	2.22
sacra	872	43.90	taco	692	0.00
saga	944	28.57	tacón	710	6.67
sagaz	965	40.91	taller	658	4.35
sana	720	6.82	talón	761	9.09
sapo	675	4.35	tapa	637	0.00
saque	818	26.19	tapiz	735	2.38
savia	930	20.00	tarro	775	9.52
saña	1049	68.18	tasa	691	13.64

Appendix C

Word Stimuli used in Experiment 3; corresponding mean correct Response Latencies (Mean RT) and Percentage of Errors (%Err)

High Frequency of the first Bigram			Low Frequency of the first Bigram		
	Mean RT	%Err		Mean RT	%Err
cuba	743	5.26	daga	835	27.78
cubo	673	2.56	dama	690	2.56
culo	674	0.00	danés	924	28.95
cuna	730	5.41	dato	792	18.42
cupo	885	17.14	daño	694	2.56
cura	708	0.00	hebra	1007	35.29
miga	789	23.68	hedor	954	27.03
mili	813	72.97	heno	986	44.44
milla	900	21.62	hilo	724	2.70
millar	841	11.76	himen	1117	48.57
millón	696	2.70	hipo	835	21.62
mimo	908	25.00	hito	941	32.43
mina	870	15.79	lidia	810	18.92
mirón	830	5.41	ligue	796	7.69
mitin	1242	70.27	lino	729	10.26
pudor	746	0.00	lirio	909	13.89
puma	814	20.00	liso	655	5.13
puro	740	2.70	litio	1012	39.47
puta	706	5.26	locuaz	916	35.14
puñal	743	2.63	lona	801	24.32
puño	722	0.00	losa	894	21.05
tajo	789	28.21	lote	775	10.81
tapia	848	23.08	líder	713	0.00
tapón	698	0.00	necio	904	20.51
taza	659	2.63	neto	901	26.32
tibio	843	16.67	rabia	717	2.56
tigre	694	2.56	radar	776	13.16
tilo	854	59.46	rama	762	2.63
timo	799	18.42	rapaz	899	16.67
timón	818	8.11	raso	873	23.53
tino	842	36.11	rata	640	0.00
tiro	803	11.43	rayo	778	10.81
tirón	743	5.56	raza	693	8.11
tiza	723	5.26	raíz	717	2.63